A CALORIMETRIC DETERMINATION OF THERMAL PROPERTIES OF SATURATED WATER AND STEAM FROM 0° TO 270° C.

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ABSTRACT

A description is given of the method, apparatus, measurements, results, and formulations involved in the work on steam which has been completed to date at the National Bureau of Standards.

The method has been developed in accordance with the principles set forth in a rigorous analysis of the thermodynamic processes involved in a change in state of a saturated fluid.

The apparatus has been designed and built to provide a means for accurately controlling, observing, and accounting for the amount, the change in state, and the change in energy of a sample of water.

The observations have been carried out as a systematic series of experiments in the range from 0° to 270° C. (to 55 atmospheres pressure), yielding as a result the values of three characteristic thermal properties of the saturated fluid.

The formulation of the results establishes the values of heat content, latent heat, and entropy and constitutes an exhibit of the thermal behavior of saturated steam in the region covered by the experiments.

The results are assembled in a coherent, consistent table of the properties of steam, available as a foundation for a more complete steam table.

It is found that when reduced to a uniform basis, after critical study and analysis, most of the source data on saturated steam are in satisfactory accord.

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I. INTRODUCTION

The measurements here described were undertaken to meet a need for more data to be used as the basis for a steam table suited to present and prospective demands of steam-power engineering. The work was initiated as a result of the conference [1] of engineers and physicists which was held in Cambridge, Mass., on June 23, 1921. The program of experimental work undertaken by the Bureau of Standards was a part of a greater project which has been sponsored and largely supported by the American Society of Mechanical Engineers. Harvard University and Massachusetts Institute of Technology have cooperated in this project by undertaking definite programs of investigation.

The importance of international accord as to the basis of steam-power calculations has been recognized here and abroad. This has resulted in the international cooperation of engineers and investigators in the correlation of their work, with the object of ultimately developing a universally acceptable steam table.

In the program of securing new data for the revision and extension of the steam table the part which was undertaken by the Bureau of Standards is concerned with the energy changes which occur in the fluid, water, when a mixture of the liquid and vapor phases is subjected to changes of state. The thermal properties which characterize these changes may be determined by calorimetric measurements made upon samples of the fluid under its own vapor pressure, or, in other words, at the saturation limit. In the present work a systematic series of such calorimetric measurements has been carried out. A group of thermal properties has been determined which constitutes a calorimetric survey of the behavior of steam in the saturation region extending from 0° to 270° C. The theory of the experimental method employed and the analysis of the physical processes have been given in two publications,[2] of which the latter gives the more general and complete theoretical treatment. Brief descriptions showing the development of the design and construction of the equipment, the progress of the experimental work, and the tentative results obtained, have appeared from time to time as progress reports.[3] Because of the tentative nature of the results previously published, the work has been described only briefly. In this report of the measurements completed to date, a more complete account will be given of the design, construction, and use of the apparatus and of the reduction and formulation of the results.

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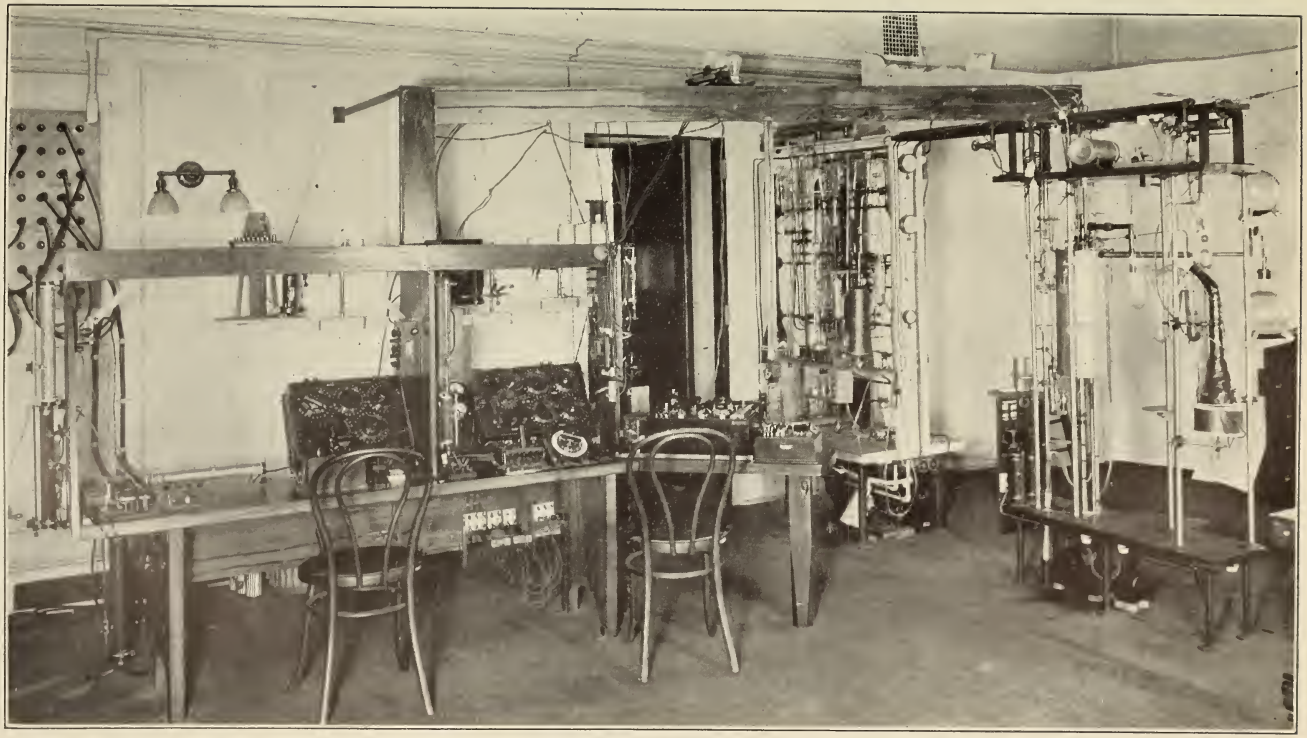
[1] Mech. Eng., **43**, p. 557; August, 1921.

[2] J. Opt. Soc. Am. & Rev. Sci. Inst., **8**, No. 4, p. 519; 1924; B. S. Jour. Research, **4**, No. 5, p. 609; 1930.

[3] Mech. Eng., **45**, No. 3, p. 168; 1923; **46**, No. 2, pp. 81, 83; 1924; **46**, No. 11a, p. 808; 1924; **47**, No. 2, p. 106; 1925; **48**, No. 2, p. 152; 1926; **49**, No. 2, p. 162; 1927; **50**, No. 2, p. 152; 1928; **51**, No. 2, p. 125; 1929; **52**, No. 2, p. 127; 1930.



Electrical measuring instruments Still for purifying water Assembled calorimeter

FIGURE 1.—*General view of assembled equipment*

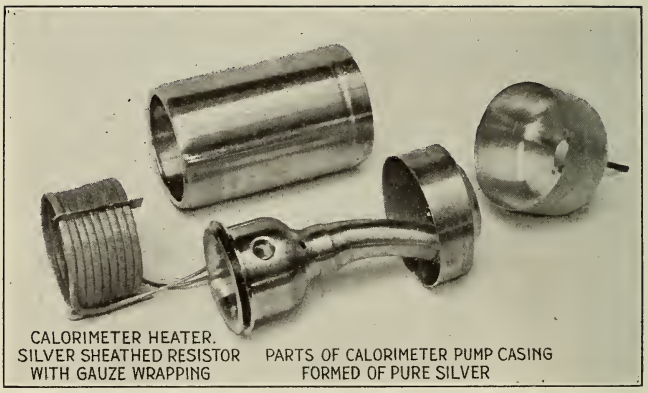


FIGURE 3.—*Parts of pump casing and calorimeter heater*

Recently a study [4] has been made of published source data from previous calorimetric work on water and steam in the saturation state. It is therefore unnecessary to include in this paper any of the details of that study, but the revised values and the appraisals there made serve as the basis for their comparison with the results of this present group of measurements. These results have been formulated into an exhibit of the calorimetric behavior of water as saturated liquid and vapor with which other groups of source data may be correlated. This formulation, starting with liquid water under its own vapor pressure at 0° C., extends up to 270° C., and for this range constitutes a consistent, coherent table of observed thermal properties of saturated steam, and may be regarded as an available foundation for a more extensive formulation of the properties of steam.

II. GENERAL DESCRIPTION OF METHOD AND APPARATUS

Before attempting to describe any of the details of design, construction, and operation of the apparatus, which, it must be admitted, is somewhat complicated, the general scheme will be outlined. A general photographic view of the equipment as assembled in the laboratory for operation is shown in Figure 1.

1. METHOD

The method makes use of a single calorimetric equipment by means of which measurements are made to determine several of the important thermal properties of the fluid. A sample of the fluid in a closed container at some chosen saturation state is heated electrically to some other chosen saturation state, or else is withdrawn either as saturated liquid or as saturated vapor. The energy required for each of these three processes is added and measured electrically. The amount of energy added per unit mass is characteristic of the particular experimental process observed. The group of measurements yields essentially the heat content or enthalpy, together with several other important properties, and establishes the thermal behavior of the fluid in the region covered by the survey.

2. APPARATUS

The apparatus consists essentially of a calorimeter which provides a place where a sample of water may be so isolated from other bodies as to enable its amount, state, and energy to be accounted for. The sample may be made to pass through a chosen, accurately determined change of state, while the accompanying gain or loss of energy is likewise accurately determined. The design of the apparatus provides for several such experimental processes selected for their physical simplicity and for their fitness to exhibit the thermal behavior of the fluid. The arrangement of the apparatus is shown in Figure 2.

A quantity of water, part liquid and part vapor, is inclosed in a metal calorimeter shell. The water is circulated rapidly about the interior in such a manner as to distribute heat and promote close approximation to thermal equilibrium. An electric heater continually bathed with flowing water provides a means of adding measured

[4] B. S. Jour. Research, 5 (RP210), p. 481; 1930.

energy which is speedily distributed throughout the calorimeter system. Outlets with valves provide for the introduction or withdrawal either of liquid or of vapor. Detachable receivers suitable for weighing are connected to the outlets to hold the samples of water transferred.

For confining the energy, the calorimeter is well insulated from the influence of external sources of heat and cold. In operation the temperature of an enveloping shell is kept very close to that of the calorimeter shell itself. The heat which passes by leakage to or from the calorimeter system is accounted for as a small correction which is determined. The energy consumed in circulation and added to the system as heat is another small correction which is determined.

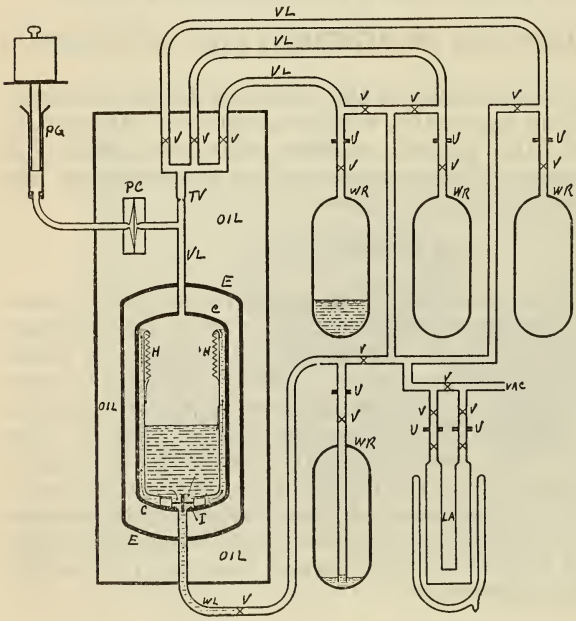


FIGURE 2.—*Diagrammatic scheme of calorimeter equipment*

C, calorimeter shell.
E, envelope shell.
I, water-circulating pump.
H, calorimeter heater.
WL, water line.
VL, vapor line.
WR, water receiver.
OIL, oil bath.
TV, throttle valve for steam.
V, valves.
U, unions.
VAC, vacuum line.
PC, pressure capsule.
PG, pressure gauge.
LA, liquid air trap.

Means are provided for observing the following quantities: (*a*) Temperature of the calorimeter and contents; (*b*) vapor pressure in the calorimeter; (*c*) mass of fluid contents of the calorimeter; and (*d*) energy added to the system, including electric energy converted to heat and the small corrections for thermal leakage and circulation.

The apparatus is designed to permit three special types of measurements to be made. In the ideal case of perfect manipulation and control of experimental conditions these would consist essentially of observations of the following processes: (*a*) Heating with fixed amount of contents (heat-capacity determinations); (*b*) isothermal expansion by adding heat, evaporating liquid, and removing saturated vapor (latent-heat experiments); and (*c*) isothermal expansion by adding heat, evaporating liquid, and removing saturated liquid.

3. RÉSUMÉ OF THEORY OF METHOD

By using the results of the published theory [5] the measured quantities may be expressed algebraically in terms of familiar thermal properties. The experimental determinations of heat capacity of a

[5] B. S. Jour. Research, 4, No. 5, p. 609; 1930.

sample of water give as a result the increase in the quantity $H-L\frac{u}{u'-u}$ over the observed range of temperature, in which H and L denote, respectively, in energy units, the heat content of saturated liquid and heat of vaporization per unit mass, and u and u' denote specific volume of saturated liquid and vapor, respectively.

In the latent-heat experiments we measure the energy which is added when water is evaporated and withdrawn as saturated vapor at constant temperature. This amount of energy per unit mass is equal to $L+L\frac{u}{u'-u}$. The ratio $\frac{u}{u'-u}$ is the fraction of a unit mass evaporated but remaining within the calorimeter when unit mass is withdrawn.

The quantity $L\frac{u}{u'-u}$ is complementary both to the determinations of heat capacity and to the determinations involving vapor withdrawal when the values of H and L are desired. This quantity is measured conveniently at any desired temperature by observing in supplementary calorimetric experiments of the third type the energy required to produce the necessary evaporation when a certain quantity of saturated liquid is withdrawn.

Thus, the three different types of experiment yield values of three quantities referred to certain temperatures. These quantities, $H-L\frac{u}{u'-u}$, $L+L\frac{u}{u'-u}$, and $L\frac{u}{u'-u}$, are denoted by the symbols, α, γ, and β. From these are derived finally the values of heat content of saturated liquid, H, heat content of saturated vapor, H', and heat of vaporization, L. In addition to these three energy quantities, characteristic of the fluid, there also may be derived from the calorimetric data the entropies of the saturated liquid and vapor; and by use of vapor-pressure data, obtained from other sources, specific volume and internal energy may be calculated.

The properties of water at the saturation limit which may be derived from the calorimetric data and the formulas by which these derivations are made are as follows:

$$H=\alpha+\beta$$

$$H'=\alpha+\gamma.$$

$$L=\gamma-\beta$$

$$\Phi=\int\frac{\alpha d\Theta}{\Theta^2}+\frac{H}{\Theta}=\int\frac{d\alpha}{\Theta}+\frac{\beta}{\Theta}$$

$$\Phi'=\Phi+\frac{L}{\Theta}$$

in which the following notation is used:

H = Heat content per unit mass of saturated liquid $(\epsilon+\pi u)$, referred to an arbitrary zero.

H' = heat content per unit mass of saturated vapor, referred to the same zero as H.

L = heat of vaporization per unit mass $(H'-H)$.

u = specific volume of saturated liquid.

u' = specific volume of saturated vapor.

$$\left.\begin{aligned} \alpha &= H - L\frac{u}{u'-u} \\ \beta &= L\frac{u}{u'-u} \\ \gamma &= L\frac{u'}{u'-u} \end{aligned}\right\} \text{measured quantities.}$$

Θ = temperature in centigrade absolute.

ϵ = internal energy per unit mass.

π = vapor pressure at saturation limit.

Φ = entropy per unit mass of saturated liquid, referred to an arbitrary zero.

Φ' = entropy per unit mass of saturated vapor, referred to the same zero as Φ.

III. DESCRIPTION OF CALORIMETER

The term "calorimeter" will be used here to denote that portion of the apparatus where the observed thermal process occurs. It is the part from which external influences are so isolated that the experimental processes may be accurately controlled and observed. The calorimeter is thus the relatively small part of the apparatus within which we may account accurately for energy added, amount and state of matter, and work done. It forms the nucleus around which the whole experimental equipment is developed.

The calorimeter was designed so that each of the three thermal processes previously mentioned could be separately observed. From these observations the corresponding group of thermal properties of water can be derived. Several general principles have aided in developing the design. These precepts may be enumerated as follows:

(*a*) A preliminary analytical study throws important light upon the applications of the thermal processes leading most directly to the desired results.

(*b*) Simplification of the experimental processes by refinement in the details of equipment and manipulation makes departures from the ideal experiment small or negligible, and thus promotes reliability.

(*c*) Advance consideration of the relative importance of individual refinements is more to be desired than makeshifts to account for and eliminate inconsistency of results.

(*d*) The apparatus should be moderately proportioned so as to promote accuracy and facilitate construction, assembly, and operation.

(*e*) The best available materials and workmanship are most economical in the end.

(*f*) Proof tests of materials, particular features of design, and of partly assembled portions of the whole reduce hazards to the completion of the work.

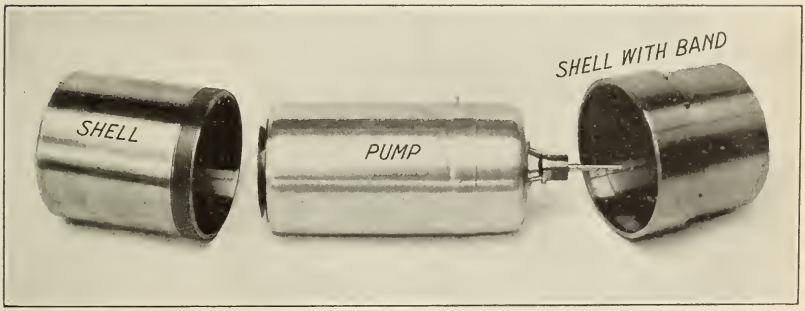


FIGURE 4.—*Calorimeter pump and shell*

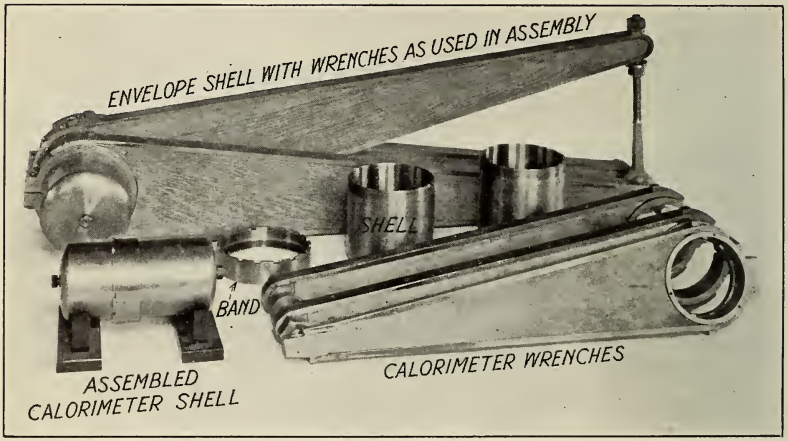


FIGURE 5.—*Wrenches and manner of assembling shells*

These principles may appear so obvious as to need no mention, but they suggest ideals to be sought and are recalled at this point to indicate a background against which closer details may be viewed in proper perspective.

1. CALORIMETER SHELL

The purpose of the calorimeter shell shown at *C* in Figure 11 is to provide a receptacle or reservoir for the sample of water under observation. This shell is cylindrical in shape, having spherical ends, and is made of an alloy of 80 per cent copper and 20 per cent nickel. It contains, in addition to the water, the parts which serve as operating organs. These consist of a circulating pump, electric heater, etc., and will be described presently. To provide for installation of these parts, the shell is made with a joint normal to its axis. The two main portions of the shell were shaped by cold drawing. Each is accurately machined, one with a right-hand and the other with a left-hand thread at the joint. The parts are brought together by a Monel-metal band threaded correspondingly. The joint is made tight by the pressure which a tongue on one portion exerts on a gold-wire gasket lying in a groove in the other portion. To assemble this joint three special powerful wrenches, shown in Figure 5, were provided. Two of these are clamped about the smooth cylindrical surfaces, while the third wrench engages a series of rectangular notches in the Monel band. The two clamps are yoked together at the outer end, and a threaded draw bar provides the driving force in the final closure of the joint. In this operation sufficient initial stress must be developed in the band to insure a perfect seal against the vapor pressure of the water at any subsequent operating temperature. The amount of force with which the shell is drawn together was determined by making actual proof tests with saturated steam at a higher temperature than the experiments are intended to reach. As expected, these proof tests showed that the joint acted as a safety valve which would open at a rather definite steam pressure and close again after the pressure was moderately relieved.

The interior of the shell is heavily plated with silver, burnished after each successive plating. This is for the purpose of avoiding contact of the water with the base metal of the shell, silver being more resistant to hot water than the copper-nickel alloy. The exterior is likewise silver plated to give it a bright surface.

The various plugs and fittings which serve as ducts for tubular connections with the outside and for electric power connections are made of alloys of silver and sealed with gold gaskets in tongue-and-groove joints.

2. CIRCULATING PUMP

The purpose of the circulating pump is twofold. It maintains a rapid circulation of the liquid about the walls of the calorimeter shell for distributing heat and thus promotes thermal equilibrium. It provides at the same time a source of liquid at the top of the calorimeter for keeping the heater surface bathed with water spread out in a thin, flowing stream.

Vigorous circulation lessens the time required to equalize the temperature of calorimeter and contents and permits observations of steady initial and final temperatures to be made promptly.

Another advantage of the rapid distribution of heat is that during the time when heat is being added electrically, temperature gradients on the calorimeter surface are kept small. The mean temperature of the surface may be obtained with reference to the opposed envelope surface by means of distributed thermoelements for accurate evaluation of the thermal leakage.

The method of bathing the heater by a continuous thin flowing layer of liquid brings the evaporating surface close to the energy source, and thereby accomplishes quiet evaporation, producing dry saturated vapor with very little distrubance of temperature in the entire system. This feature will be discussed later.

The construction of the pump is indicated in Figures 3 and 11. It is of the centrifugal type, specially designed for the requirements of this particular case. The pump circulates about 6 liters of water per minute, the equivalent of the entire contents passing around every 5 seconds. The flow circuit divides at the top, the larger part following the wall of the shell and the rest flowing through a port, down over the heater, and thence down to the inside storage space. To circulate the two streams, one of large flow and low head and the other of small flow and greater head, the pump wheel or impeller is made in two parts, rotating together and delivering into the same casing. As a result of tests of the characteristics and efficiencies of a series of model pumps, this final design combining two stages in parallel, each of different characteristics, was developed and was found to give satisfactory heat-distributing capacity with a tolerably small power input.

The energy consumed in the pump is dissipated as heat added to the calorimeter system and is objectionable if its amount is indeterminate or too great. Too large a pump energy input would interfere with the accurate observation of the initial and final temperatures. Too much fortuitous variation in the pump energy would impair the accuracy of accounting for energy from this source.

The normal speed of the pump wheel is 900 r. p. m. This speed was changed in certain experiments as found desirable. The method of speed control will be indicated later. The power input is determined calorimetrically and varies from 0.05 to 0.10 watt, depending on controlled conditions. The flow in the inner circuit over the evaporator and through the stage which maintains the head for keeping the main flow channel full is about 1 liter per minute. The flow in the main channel is about 5 liters per minute. The efficiency in pumping the water from intake to discharge at the top of the calorimeter was found to be about 28 per cent. The construction of a pump of this size and character designed to operate continuously in water up to 300° C., with no other lubrication of the running parts than that furnished by the water, built of materials which would be unaffected by the action of the water, involved some interesting problems.

The impeller runs on ball bearings of iridium alloy. The balls are about 1.2 mm in diameter, 10 balls in the lower and 7 in the upper bearing. The main part of the runner is built up of silver-palladium alloy. The shroud and clearance ring of the upper stage are made of one piece of silver-gold alloy riveted to the runner. The vanes are machined to stream-line curves. The lower stage has neither shroud nor clearance ring.

The five parts of the pump casing and flow channels are formed of pure silver. These parts go together with well-fitting slip joints fastened, where necessary, with pins. The entire pump, discharge tube, and flow-channel casing form a unit which, when assembled, is borne rigidly within the calorimeter shell on three supports of stream-line form, machined from a solid piece of silver-gold alloy, which fits the central opening at the bottom of the shell.

The pump runner is driven by a square on the lower end of the main runner shaft which engages the square in the upper end of the tubular propeller shaft of silver-palladium alloy. This propeller shaft extends down through the lower tubular support of the shell and on down to the stuffing box where it engages the stuffing-box shaft of hardened tool steel with another square joint.

3. STUFFING BOX

The stuffing box, built to provide for the rotation of the drive shaft for the calorimeter pump without permitting leak of water by it, is shown at *WSB* in Figure 11. A cylindrical recess 5 mm in diameter and 12 mm deep in the Monel body was fitted closely with two small ring-shaped packing retainers. The one which goes above the packing is of silver-palladium alloy and the one below of phosphor bronze. These retainers fit the 1-mm hardened-steel drive shaft within 0.01 or 0.02 mm on the diameter, so that very little space is left through which the packing can flow. The packing consists of soft kid-leather washers impregnated with paraffin. Pressure is transmitted to the packing in the recess by means of an appropriate number of cupped washers of spring steel. These are compressed to the desired degree by means of a gland threaded into the body of the stuffing box. In order that there shall be no leak it is necessary that the hydrostatic pressure in the packing be greater than the vapor pressure in the calorimeter. To prevent undue wear on the pump shaft the number of spring washers, the method of combining them, and the amount of deformation imparted to them are adjusted to meet the needs of the experimental conditions. To avoid the difficulties of finding a packing which would be satisfactory at high temperatures, the stuffing box is placed outside the lagging and water cooled. The size of the pump shaft where it engages the packing was reduced to 1 mm to cut down the wear. Below the packing the shaft is larger, and is provided with a ball bearing to take the downward thrust. The race for this bearing is attached to the outside of the body of the stuffing box by a threaded joint and can be removed readily for examination of the packing. A brass collar prevents undue upward motion of the shaft. Power for driving the pump is supplied from below, as will be more fully described later, and transmitted to the pump shaft by a hollow drive shaft having squared slip joints to provide easy assembly yet positive drive.

4. ELECTRIC HEATER

The electric heater furnishes the means by which the major portion of the measured energy is added to the calorimeter system. So far as the heat-capacity experiments of the first type are concerned, no extraordinary restrictions as to characteristics of this part are necessary, as the exact path by which the change from an initial to a final temperature occurs is of no importance if the energy account is faith-

fully kept. In the case of evaporation experiments, and particularly those of the second type, much may depend on the way in which the energy is supplied and utilized in the evaporation process. The question as to the actual state of steam used in latent-heat measurements is the moot point which has frequently been raised as affecting the dependability of published values. If the energy could be supplied exactly at the surface where it is required for evaporation, none of it would go to superheating either the liquid or the vapor. Evaporation would then proceed quietly and dry saturated vapor would be produced. In this calorimeter the electric heater, which is, in fact, an evaporator, has been developed to effect quiet evaporation and the formation of dry saturated steam with very little disturbance of thermal equilibrium in the calorimeter and contents.

The evaporator heater as installed is shown in section at *H* in Figure 11 and photographically in Figure 3. In this electric heater a resistance wire of constantan 0.4 mm in diameter, with gold leads of the same size, forms the resistor. This resistor is insulated by embedding it tightly in dry clay which completely fills the pure silver tubular sheath. The portion of the sheath containing the resistor is flattened to a thickness of about 2 mm. The end portions containing the gold leads are drawn to a diameter of about 2 mm. The flattened portion is wrapped spirally with a strip of pure silver fine-wire gauze, fastened by spot welding at a number of points. The flat resistor portion is then bent into the final helical form as shown and the leads bent so as to pass downward and out of the shell through the fitting.

The purpose of the gauze wrapping is to insure even distribution of the stream of water which flows through the annular port, and thence down as a thin sheet enveloping the evaporator.

The resistance of the completed heater is about 10 ohms. The insulation resistance between the resistor element and the silver sheath was found to be about 90 megohms when cold.

The evaporator when installed is held in its central position just below the water port by a 3-armed silver support carried on the central portion of the discharge tube of the pump. The water is led from this port by guides of silver gauze and brought to the very top of the evaporator. The excess of liquid which flows off the evaporator is led quietly down into the central reservoir by a similar guide or apron of gauze.

5. ENVELOPE

The chief purpose of the envelope which surrounds the calorimeter shell is to provide a receptacle in which the shell may be installed to isolate it from adventitious or fortuitous sources of energy.

We may regard the space between the calorimeter shell and the envelope as a barrier to heat flow, pervious to only a slight extent. The necessary metal connections between the calorimeter and its surroundings furnish other restricted channels for heat flow. The thermal-leakage rate may be made small by refinement of construction, but can only be annulled completely by avoiding temperature difference. This may not be actually possible, but by first making the thermal insulation very good and then in operation keeping the temperatures under control it is possible to keep the heat leak extremely small in all cases and to account accurately for the unavoidable small heat leak which does occur. Provision has been made for both these measures in the present calorimeter, as will presently be shown.

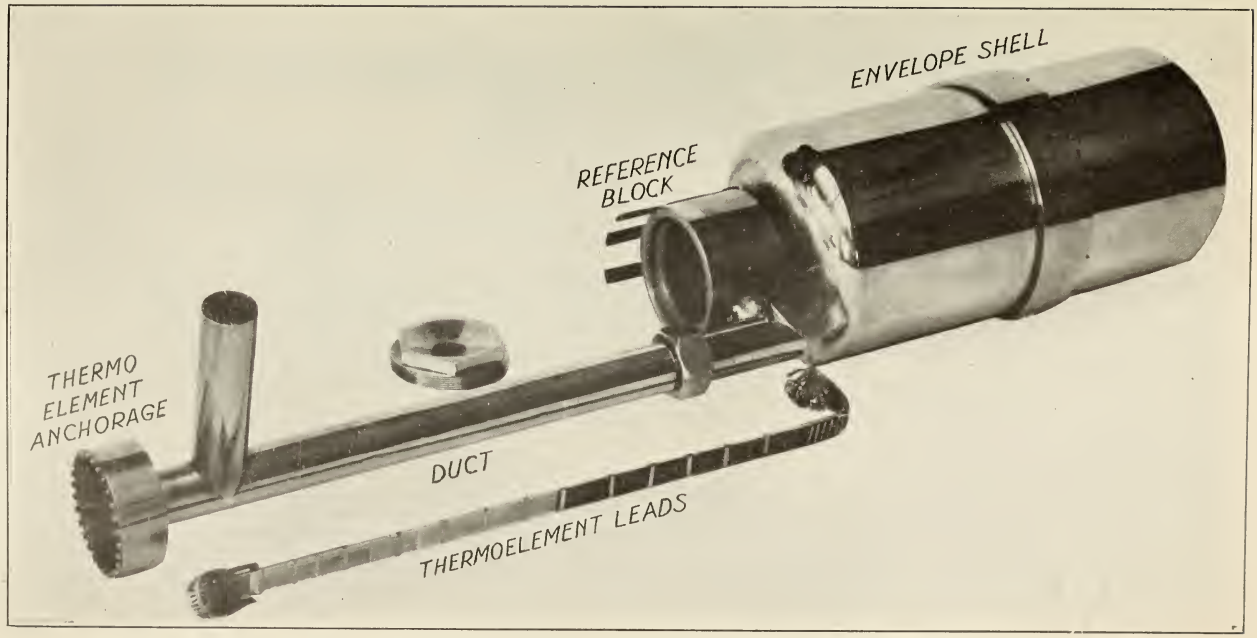


FIGURE 6.—*Envelope shell with reference block, duct, and thermoelement leads*

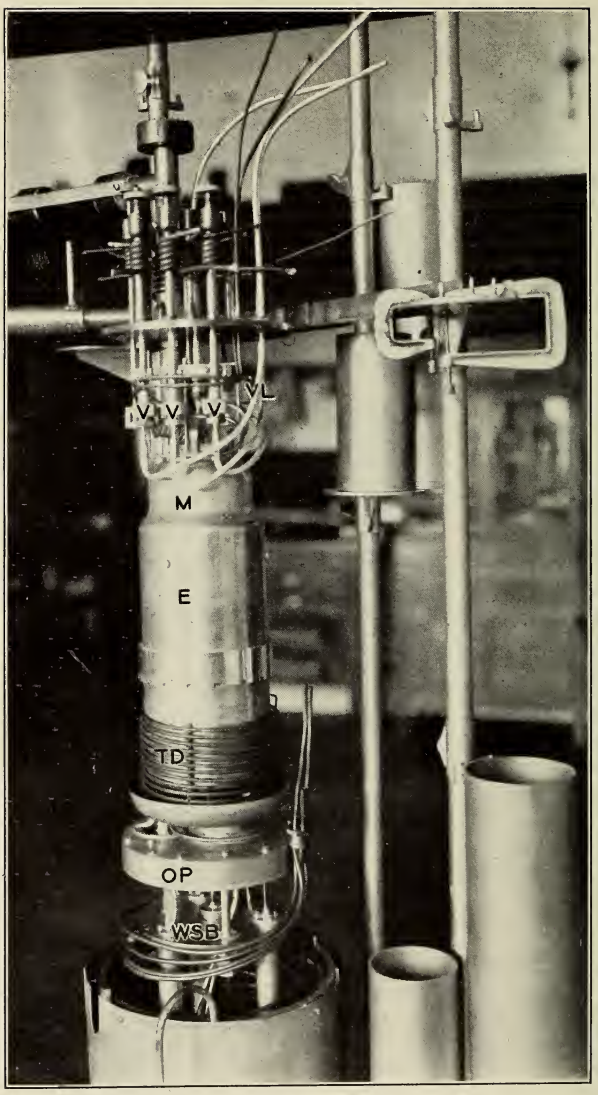


FIGURE 7.—*Partly assembled calorimeter*

E, Envelope shell; *M*, mantle for reference block; *TD*, thermoregulator dilatometer; *V*, shut-off valves; *VL*, vapor lines; *WSB*, water stuffing box; *OP*, oil pump.

The envelope is shown at *E* in Figure 11. This outer shell is very similar in construction to the shell of the calorimeter. It is of the same material, made in two parts, assembled in the same manner. This shell is made strong as a precautionary measure in case the inner shell should fail to hold the water sample under pressure.

The calorimeter shell is supported axially within the envelope by means of two tubes of silver-palladium alloy, one at the top and one at the bottom. Besides furnishing strong stiff supports, these tubes serve also as channels for transfer of fluid to or from the calorimeter, either as liquid or vapor. The lower tube also incloses the propeller shaft of the circulating pump. The upper tube serves as an opening through which a tool may be introduced for adjusting parts. The metal of these tubular supports was chosen because it possessed the desired characteristics of resistance to action of hot water, strength, thermal resistivity, and satisfactory workability.

To avoid the danger of injury to the delicate supporting tubes by accidental shock to the system when in place, six metal pegs are fixed in the wall of the outer shell, extending radially inward nearly to the surface of the inner shell but not touching it. These are placed in two planes near the top and bottom of the cylindrical part of the inner shell and are so adjusted in length as to prevent any eccentric displacement which would endanger the supporting tubes.

Thermal leakage may take place by either of four types of heat flow, namely, radiation, solid conduction, gaseous conduction, and convection. The first of these, radiation, is made small by silver plating and polishing the outer surface of the calorimeter shell. This finish has a tolerably low emissivity in the temperature range of these experiments.

Conduction through the metal parts extending across the insulating space is kept within bounds by choice of materials and proportions of the necessary supporting tubes and electrical leads. The supports have already been described above. The electrical leads which contribute to thermal leakage comprise 21 chromel and 14 copel thermoelement wires each 0.1 mm in diameter. Each of these materials has low thermal conductivity, and these leads contribute little to the total heat leak. The electric current and potential leads are a larger factor. These are of gold wire. The current leads are about 0.6 mm in diameter and about 4 cm long. The potential leads are about 0.2 mm in diameter and 8 cm long. They are disposed of in the envelope space about as shown in Figure 11.

Heat leak by gaseous conduction and convection was dealt with at first by providing means for evacuating the envelope space to a low residual-gas pressure of about 0.0003 mm of mercury. At this pressure the heat leak by this path is insignificant. The calorimeter was operated this way during much of the earlier work at moderate temperatures. At temperatures of 200° C. and over, trouble developed due to leaks appearing in the envelope system surrounded by oil. Presence of the small amount of oil which penetrated into this evacuated space produced thermal effects which were baffling until finally traced to their cause. After contending with this difficulty for some time it was decided to discontinue the evacuation of the envelope. Instead, it was filled with nitrogen at about atmospheric pressure. This practice gave a slightly greater thremal-leakage coefficient, but inasmuch as this coefficient was determined as a

part of the systematic routine and the actual heat-leak correction made in every experiment, a small percentage change in an already extremely small correction term was of no consequence.

Supplementing the above-mentioned features of thermal insulation of the calorimeter there is a thermometric device for indicating the relative temperatures of calorimeter and envelope surfaces and also a means for controlling these temperatures. The thermoelements which serve for the first of these form a part of the whole thermometric system which will be described in detail presently. The thermal control bath which surrounds the envelope is the medium for effecting temperature control will next be described.

6. CONTROL BATH

The control bath as shown in Figure 11 is contained in a brass casing, which, when assembled, supports the calorimeter in its envelope, through the axial connecting tube at the bottom. The bottom of the bath casing is a circular brass plate which is supported by three flattened tubular columns. These columns rest on a lower deck, which is a part of the outer casing which holds the lagging. This lower deck is borne on a main support of three columns which thus carry the main calorimetric unit.

The somewhat involved construction of these inclosures was made necessary in order to provide in advance for an assembly or dismantling without unnecessary disarrangement of delicate or remote parts. This precaution has proved a great advantage, when, in operation, either failure of a part or need for change or readjustment have necessitated access to more or less remote points inside.

A mineral oil of suitable viscosity and flash point is circulated in the bath by the path indicated in Figure 11. A centrifugal pump drives the oil about this circuit. Each of four electric-heater units supplies energy for some specific purpose. The one for principal heat supply furnishes most of the heat which escapes to the outside and part of that which is used to raise the temperature of the bath. This so-called "main heater" is located on the outer wall of the bath casing. It is made of nichrome wire, 0.8 mm in diameter, wound first in helical form, then flattened to a ribbonlike coil. After the outer wall of the bath casing had been covered with a thin layer of alundum cement baked hard, this heating element was wound on and another coat of alundum cement applied to hold it in place. The two windings have a resistance of 10 ohms each and can be used either singly, in series, or in parallel. This heater will, of course, not produce a quick response in the bath to a change in current. To provide for quick response an "auxiliary heater" is installed in the upper portion of the oil space above the envelope shell. This auxiliary heater is a copper-sheathed, clay-insulated unit similar in principle to the calorimeter heater, but proportioned and shaped for this place. Its resistance is about 10 ohms.

To provide for automatic regulation of the bath temperature a third or "regulating heater" of 10 ohms, similar in construction to the one just described, was installed in the oil-return flow just ahead of the pump intake. The current in this heater is automatically varied to maintain constant temperature in the bath by the thermoregulator which will soon be more fully described.

A fourth heater called the "central heater" is an auxiliary heater attached to the fitting on the central tube at *CH* in Figure 11. This enables the operator to keep the upper end of the central supporting tube of the calorimeter at a higher temperature than the calorimeter, so as to avoid condensation. The central heater is of the clay-insulated copper-sheathed type, wound spirally on a core of copper, to which it is hard soldered. This core is clamped to the fitting which it is desired to heat.

A refrigerating coil is installed in the bath to permit operation at temperatures down to 0° C. This consists of a tube, as shown at *RC* in Figure 11, and may be used to carry carbon dioxide, cooled by throttling from high pressure. By connecting the refrigerating coil to the water supply it can be used to cool the system after experiments at high temperature.

The thermoregulator is actuated by an oil dilatometer in which the variation of temperature causes motion of a mercury column in a small tube, thus making or breaking an electric circuit. This impulse operates a relay which effects the change in heating current. The thermoregulator is of the selective-setting type long used in this laboratory. When heating up, a valve is left open, permitting the escape of expanded fluid. When the desired temperature is reached the valve is closed, heating currents are readjusted, mercury contact finally set, and the temperature is then automatically held.

The dilatometer of the regulator is a long thin-walled tube wound in helical form and installed in the oil stream where it meets the envelope shell, as shown at *TD* in Figure 11.

The insulating material used for lagging is calorox. No attempt was made to make the heat leak from the bath very small by using great bulk of lagging. It was thought more expedient to conserve space and weight by wasting a little more electric power. The outer casing is water-cooled to keep it from getting too hot to the touch.

The various connections extending up more or less rigidly from the calorimeter unit emerge through easily fitting tubular wells in the top of the control-bath casing. This permits near closure of the oil space, at the same time allowing for differential expansion of the parts. Flexible connections are brought out through tight fittings. Special wells are provided through which the resistance thermometers are inserted into their receptacles, yet to be described.

The control bath is designed to conserve space and heat capacity by utilizing the circulating oil as a medium for rapid transfer of heat rather than as a heat reservoir. It is necessary to provide for the change in volume of the oil over the temperature range used. An outlet at the top leads through a water-cooled tube to a trap with two oil reservoirs, each of 3 liters capacity. The supply flask is above, inverted, with spout below the overflow. The other is below to receive oil which overflows. This arrangement keeps the oil level at a definite height in the wells, whether temperature is rising or falling.

7. THERMOMETRIC INSTALLATION

Temperatures at various chosen points on the calorimeter and envelope are observed by the combined use of platinum resistance thermometers and thermoelements. A heavy copper reference block located in the bath at *R* in Figure 11 serves as the thermal union

between the resistance thermometers and the reference junctions of the thermoelements. The thermometers thus measure the temperature of the reference junctions, and the thermoelements indicate the small temperature differences which exist between the reference block and the principal junctions located at the chosen points.

The three thermometers fit into copper receptacles which are hard soldered to the reference block. Thirteen thermoelements, each having reference junctions on this same block, have principal junctions at points on the calorimeter shell and its envelope, as shown in Figure 11. Each element is made of 0.1 mm. diameter chromel and copel wires, stranded so that two copel and three chromel wires lead to the junctions. Each element has three junctions—a principal one at the place where indication of the temperature is desired and two reference junctions on the reference block. From these gold wires lead to the outside. A diagram of a single thermoelement is shown in Figure 8.

Copel-chromel elements were chosen because of their comparatively high thermoelectric power and relatively low thermal conductivity.

The reference block is especially designed to avoid temperature gradients and keep all the reference junctions and resistance thermometers at the same temperature. It is attached to the calorimeter envelope through a short tube of heavy copper-nickel. From this block a similar tube extends laterally and thence by a right turn vertically upward and out of the bath, where it terminates in an air-tight insulating seal (*S*, fig. 11) for the wires, which are led out through this duct. A side connection near the top is used in the evacuation of the envelope or the filling with gas. The reference block itself is a heavy cylindrical mass of copper with circular steps inside like an amphitheater. These steps afford space for attaching the reference junctions of thermoelements. Three flat tubular copper receptacles are attached to the block to receive the spatulalike ends of the resistance thermometers which are inserted from above. This well-conducting copper mass forms a thermal union between the thermometers and the thermoelements in which only extremely small temperature gradients can persist.

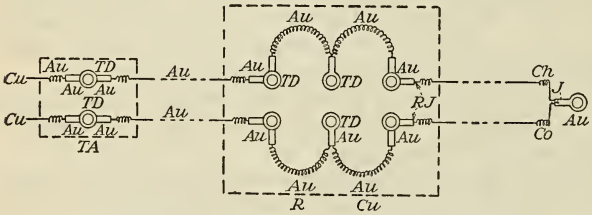


FIGURE 8.—*Diagram of thermoelement*

J, principal junction; *RJ*, reference junction; *R*, reference block; *TD*, thermoelement lead tie-down; *TA*, thermoelement lead anchorage; *Co*, copel wire; *Ch*, chromel wire; *Au*, gold wire and terminals; *Cu*, copper.

However, if left entirely unprotected from the direct influence of the oil stream, whose temperature is controlled by the automatic thermoregulator, this block would experience sensible fluctuations of temperature from the controlled mean, which would interfere with precise observations. In order to damp out these fluctuations there is provided a mantle in the form of a figure of revolution fitting the cylinder and the envelope shell at *M*, Figure 11. It moves vertically in guides so that it can be placed as shown or raised to a higher level. When in the upper position the oil passes within the mantle and bathes the reference block directly. This is the proper position when the mean temperature of the bath is being changed. When steady temperatures

are to be observed the mantle is lowered, thus keeping the reference block more remote thermally from the circulating oil and obliterating the periodic fluctuations, at the same time allowing the block to follow the mean temperature of the oil.

For insulating and supporting the thermoelements within the envelope, where this can not be accomplished merely by spacing the bare wires, mica is used. All the junctions are insulated with mica except for the principal junctions of Nos. 9 and 10, which are soldered directly to the central tube, and No. 12, which is assembled without insulation for test purposes. By making suitable connections outside the thermoelements can be used either as individuals for survey of temperature distribution or in groups to indicate average surface-temperature difference for heat-leak control. The group of five on the calorimeter can be used in series to refer the calorimeter temperature to the resistance thermometers.

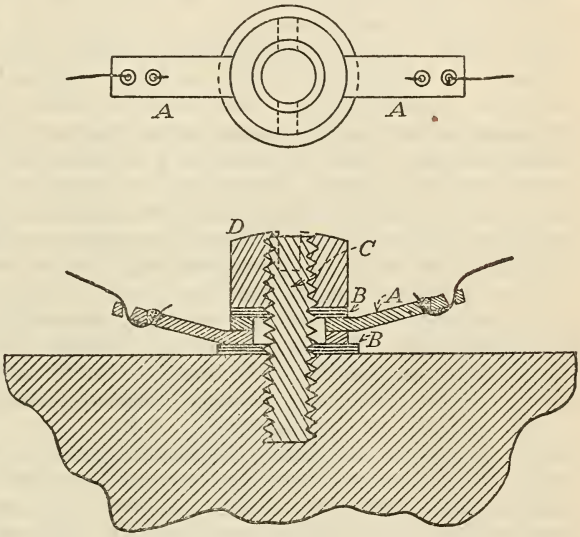


FIGURE 9.—*Details of thermoelement attachment*

A, gold terminal of thermoelement wire, lead, or junction; *B*, mica insulating washers not less than 0.1 mm thick; *C*, threaded stud; *D*, nut.

The 28 gold wires leading out from the reference junctions in the reference block are carried through a multicellular duct built up of mica strips in which each wire has its own passageway. The wires which lead downward from the reference block to the principal junctions are guided and supported by threading through appropriate thin strips of mica. The method of attaching junctions to the metal parts so as to insure electric insulation and provide at the same time good thermal union is shown in Figure 9. The gold terminal to which are hard soldered the two wires forming the junction is clamped firmly between mica washers to the metal surface under a nut threaded to a stud. By the same device connections are made between the gold wires and the reference junctions, simply leaving out any mica washer from between the gold terminals. Thermal "tie-downs" of the gold wires are made in the reference block to intercept lead conduction which otherwise might reach the reference junctions and vitiate their indications. Each wire is twice tied down before connecting with its reference junction, thus reducing the effect of lead conduction from a possible error of nearly a degree, in an extreme case, to about one ten-thousandth of this amount. A total of 80 tie-downs find place within the reference block, and a total length of about 6 m of bare

wires, coiled in helical spirals, is accommodated in the 32 cm^3 of space within this block, requiring considerable care in stowage to keep them all clear of each other. After assembly the whole system of insulated thermoelements showed an insulation resistance of several megohms to the calorimeter unit at 500 volts.

The thermoelements are made up of fine stranded wires so that they will have appropriate resistance and still be sufficiently flexible to be manipulated into suitable shapes for stowage. The total series resistance of the group consisting of elements Nos. 1 to 5, inclusive, is about 100 ohms. This resistance gives critical damping with the potentiometer and galvanometer used for observing. The resistances of the other combinations used are made up to similar total values by series resistance coils on the instrument board.

The copper ring (*TA*, fig. 11) furnishes an isothermal anchorage for the junctions between the gold lead-out wires and the copper wires which lead over to the instrument board. These circuits are entirely of copper to avoid parasitic thermal emf's. Two special switches, each of copper, were built to permit the individual thermoelements to be quickly connected to the potentiometer in the desired combinations. One of these is a double-pole 12-throw dial switch and the other a quick double-throw 6-pole knife switch. Where soldered joints were made, special care was taken to insure against thermal gradients in the joints. Every precaution was taken to reduce parasitic thermal emf's in the measuring circuits to a negligible amount.

Four platinum resistance thermometers, specially constructed for this purpose, were used as working standards for the temperature measurements. These are of the 4-lead potential-terminal type. They are made small and compact to fit the receptacles described above. The platinum windings were of 0.05 mm diameter, wound seven turns to the millimeter on a flat plate of mica notched at the edges to receive the wire. The windings occupy a length of about 10 mm. The thermometers are incased in platinum sheaths 0.5 mm outside thickness, 5 mm wide, and 60 mm long. These sheaths are hard-soldered to tubes of copper-nickel, 3.2 mm in diameter, through which the gold-lead wires threaded through mica strips are led out to the seals at the top, where copper wires are joined on.

The platinum windings were annealed by flashing, using an electric current of short duration sufficient to heat the wires to redness momentarily.

The thermometric reference block is closed at the top by a flexible annular diaphragm of silver to allow freedom for differential expansion between the outer envelope and the suspended calorimeter shell with its supporting tubes. The top of the block is terminated by a Monel ring hard-soldered to the copper, having a blunt-edged flange upon which the silver diaphragm is clamped by the threaded nut bearing against a washer. At the inner edge the diaphragm is similarly clamped to the fitting which joins the supporting tube below and connects with the distributing tube above, through a union.

8. THROTTLE AND REHEAT TUBE

This device has not been used up to the present time, but as it was installed in the calorimeter from the first assembly and had some influence on the design, although left inoperative, it will be briefly described. The extension of the silver-palladium outflow tube within

the calorimeter is threaded in the lower portion of its length with a pitch of 80 threads to the inch. A plug of silver-gold alloy is fitted to this thread so that it can be placed anywhere in the threaded part. A coil consisting of 170 cm of silver tube is connected at two points of the outflow tube. By placing the plug between these points, vapor flowing out of the calorimeter is first reduced in pressure and temperature as it leaks by the plug threads, and then flows through the coil, where it is reheated by absorbing heat from the saturated vapor which surrounds the tube. This is the arrangement provided for a fourth type of experiment in which the heat content of superheated vapor would be determined.

As the calorimeter was used in the first three types of experiments, the throttling plug was left out entirely, leaving free passage for vapor up the outflow tube.

IV. ACCESSORY APPARATUS

1. FLOW LINES AND CONTROL VALVES

The flow lines provide connections between the calorimeter and the outside receivers and are used to conduct the flow in the transfer of fluid to or from the calorimeter. The lines at the bottom provide for the introduction and withdrawal of liquid, while those at the top are used in the withdrawal of vapor. Figure 2 shows diagrammatically the various paths along which liquid and vapor can be conducted and the relative positions of the control valves.

The valves used in the flow lines are all of the diaphragm type, which permits motion for operation without the use of packing and will be described later. Part of these can be operated as shut-off valves and two as throttles for reducing pressure and controlling rate of flow.

All flow lines are of silver or silver-palladium tubing. Those which are at the pressure existing inside the calorimeter are of silver-palladium, except one small silver tube at the bottom. This bottom tube emerges from the side of the lower supporting tube, in the lagging space, and leads downward near the stuffing box to the outside, as shown at *WL* in Figure 11. It serves for introduction or removal of liquid and is the only connection to the calorimeter which has to be broken for dismantling the control bath. The silver-palladium exit tube at the top of the calorimeter has two horizontal branches, one leading to a throttle valve and one to a pressure-transmitting device or pressure capsule, which will be described later. From the throttle valve a silver-palladium manifold tube leads to three shut-off valves located in the control bath. From each of these a comparatively large silver tube leads out through the top of the control bath and the lagging to a silver tempering coil which is provided with means for evacuation, through a diaphragm valve. The liquid line at the bottom leads through a diaphragm valve which serves either as a liquid throttle or shut-off, to a similar tempering coil. All four tempering coils terminate in unions which fit the threaded portions of the valves on the containers for the water. All four vacuum valves lead to a common vacuum line, which is provided with a metal trap in which water remaining in the connecting lines can be caught and weighed.

The diaphragm valves already spoken of were designed to eliminate the use of packing. One of these will be described to illustrate this feature. In the section shown at *VV* in Figure 11, it may be seen that the action which opens and closes the valve is the vertical motion of a stem relative to a seat. The face of the stem is a soft silver disk, and the seat in this type is a rather blunt but finely machined edge of silver-palladium alloy. Longitudinal motion of the stem is permitted by an annular silver diaphragm of 0.2 mm thickness, clamped to seal tightly near the outer and inner edges. Rotation of the stem is thus prevented. The portion of the stem outside the diaphragm is a cylinder fitting freely in a recess in the valve bonnet, so that the stem moves perpendicularly to the plane of the seat. Excessive flexure of the diaphragm is prevented by the metal support behind it and by limiting the travel of the stem. In this type of valve used on the containers and in the vacuum lines the motion is imparted to the stem by a differential thread arrangement. The differential screw has a square end which can be turned by a detachable key.

Each of the three shut-off valves in the bath, one of which is shown at *V* in Figure 11, is of this same diaphragm type, but the motion is imparted to the stem in a different manner. These valves have to be opened and closed as nearly instantaneously as possible, and no intermediate positions in the motion are required. Therefore, instead of the differentially threaded stem, an entirely different mechanism was designed to accomplish this purpose. Their stems are attached to vertical struts, leading outside the control bath to a spring and lever system shown at *VM* in Figure 11. By means of the adjusting screws illustrated the mechanism can be set so that any desired force of the stem on the seat will be furnished by deformation of the spring lever, *SL*. It is evident from the diagram that by a single motion of the operating lever, *OL*, the valve can be completely opened or closed. The provision by which these operations are automatically carried out at a signal from the standard clock will presently be described.

The shut-off valve in the liquid line was changed during the liquid-withdrawal experiments from the type shown at *WV* in Figure 11 to a type similar to the vapor shut-off valves in the control bath. Provision was made for the remote control of a slow-motion screw which actuated the handle of the mechanism. The opening of the valve could thus be controlled to regulate the rate of withdrawal of liquid.

The vapor throttle valve is similar to the shut-off valves, but because of the fineness of operation demanded of it, certain changes were necessary. The seat is made flat with a 0.5 mm aperture and the silver disk on the stem is made slightly conical where it engages the seat. The operating mechanism outside the oil bath was changed to the form shown in Figure 11 and was provided with a slow-motion screw to operate the valve handle. This slow-motion screw is operated from the instrument table by a positive mechanical control. The spring lever was replaced by a heavier brass one, which acts as a rigid member. All joints are made as free from backlash as possible, and the spring, *K*, is provided to take up the residual slack. For some of the latent-heat experiments at high pressures, a set of eight silver palladium disks each 0.1 mm in thickness and with 0.5 mm holes

in the centers, was introduced between the valve stem and the seat to provide more paths for vapor and thus cut down the sensitivity of the valve to motions imparted to it by the observer.

Considerable difficulty was experienced in the evolution of the throttle valves. The two described proved to be the most satisfactory of several which were tried.

2. CONTAINERS FOR WATER

The containers for the water, as shown at *WR* in Figure 11, are made of 1.6 mm silver in cylindrical form with hemispherical ends. Their capacity is about 425 cm^3. Those for use in transferring liquid are provided with reentrant silver tubes reaching nearly to the bottom. Each container is provided with an outlet tube of silver bent as indicated in the figure and leading to a diaphragm valve. The body of this diaphragm valve terminates in the male half of a union, threaded to fit any of the unions on the tempering coils. The weight of each container and its valve is about 1,000 g.

3. PUMP-SPEED CONTROL

The speed of the circulating pump in the calorimeter is accurately controlled to make the rate at which it supplies energy to the water definite and reproducible.

The long external drive shaft for this pump has squared ends which couple the pump positively to a liquid tachometer, rotating at the same speed as the pump. The tachometer, of the well-known Veeder type, is driven by a motor which draws its power from a 50-volt storage battery. The impeller maintains a column of kerosene at a height which is determined by the speed. A column of mercury in a side tube off the kerosene column is maintained at a level which also varies with the speed. In a manner similar to that of the thermostat, this mercury column, by its motion, serves to make and break an electric circuit. As a result, more or less resistance is placed in the armature circuit of the driving motor, in the direction required to maintain a constant head of mercury. The kerosene column furnishes a sensitive means for the direct observation of the pump speed, which latter is maintained practically constant by the automatic control.

To check the constancy of the pump rate, a revolution counter was geared directly to the pump shaft. Observations with this counter at infrequent intervals showed that the pump rate is maintained constant at any desired value to about 0.1 per cent.

4. TIMING DEVICES

In the α and β experiments the time of electric heating and in the γ experiments the time of withdrawal of vapor must be observed. For the first of these there was constructed a double-pole double-throw switch operated by a spring and a release which is actuated by an electric impulse from the standard clock. This automatic switch not only opens or closes within less than 0.1 of a second, but also requires the same time interval for action in either direction. In operation it was used to switch the connection from a 30-volt storage battery to either the calorimeter heater or to a spill coil having nearly the same resistance.

To provide for timing the flow in the γ experiments, the actuating mechanisms of the three previously described shut-off valves are equipped with pulley wheels rigidly attached to the operating levers and rotating about the same axes as these levers. Cords firmly attached to the wheels can be led in either direction around the wheels and thence up to a spring. The spring is permitted to operate by the release of a catch at a signal from the standard clock. The spring thus furnishes the power for opening or closing the valves at a chosen time, either individually or in any desired combination. The time required for complete opening or closing of a valve is less than 0.1 of a second.

Signals from the standard clock are received only on the exact seconds, the fifty-ninth being omitted. The key in the clock circuit is closed by the operator during the fifty-ninth second, so that the zero signal is used either for starting and stopping the power or for diverting the vapor flow. The integral number of minutes involved in an observed process is observed on a watch.

5. PRESSURE-MEASURING INSTRUMENTS

Provision was made for observing pressure, and, although no measurements are included in this report, the installation will be described. A side tube from the outflow tube just after it emerges from the vacuum space leads to a pressure capsule (*PC*, fig. 11) which is also in the oil bath to avoid condensation. The pressure capsule is made of Monel metal with a 4-cm diameter sheet Monel diaphragm, *D*, 0.08 mm thick, stretched across the capsule. This diaphragm transmits the pressure from the vapor on one side to oil on the other. The diaphragm is allowed a displacement at the center of only 0.25 mm from the mean position before coming against the solid supporting walls of the capsule. When the highest working pressure is applied, no permanent deformation of the diaphragm will result. The diaphragm, however, is sufficiently flexible for a very small pressure change to deflect it across the chamber. A measurement of the opposing pressure when the diaphragm is balanced midway in the capsule will then give the pressure of the vapor. All the Monel surfaces on the vapor side are silver plated to prevent chemical action of the hot vapor with the metal. A 0.2 mm gold-wire ring was used to make the diaphragm gas tight in the capsule. Monel screws were used in addition to the Monel case and diaphragm so that there would be no differential expansion of the parts which would cause leaks or change in tension of the diaphragm. Oil is used to transmit the pressure from the diaphragm in the capsule to a gauge of the dead-weight type with piston rotating in oil.

6. ELECTRICAL MEASURING INSTRUMENTS

The electrical measurements comprise observations of thermometer resistance, thermoelectromotive force, and electric power input.

The resistances of the thermometers are measured with a Mueller[6] bridge built by O. Wolff. The bridge coils are immersed in a thermostated oil bath. A separate commutator switch permits the observation of any chosen one of four thermometers. The bridge coils

[6] Mueller, B. S. Sci. Paper No. 288.

were recalibrated whenever it was found desirable, by the method outlined by Mueller. A measuring current of 4.5 milliamperes was used both in the calibration and in the measurements of temperature. A galvanometer scale deflection of 1 mm corresponds to approximate 0.0001 ohm, or about 0.001° C., for the thermometers used.

The electromotive forces of the thermoelements, amounting in nearly all cases to less than 20 μv are measured on a Wolff potentiometer designed by F. Wenner. By comparison with another instrument which had been calibrated at the Bureau of Standards, the corrections to the indications of this instrument were found to be negligible in the range in which it is used. When the temperature of the calorimeter is being observed, a scale deflection of 1 mm corresponds to 0.002° C. or less.

The power input is measured on a Diesselhorst potentiometer, built by O. Wolff. It was calibrated at the Bureau of Standards before, during, and after the experimental work and showed no changes of more than 1 part in 30,000. The scale deflection was greater than 2 mm per division on the last dial in the measurements on current and potential drop.

The standard cells to which the potentiometric measurements are referred are Eppley unsaturated cadmium cells. They are kept in a cork-lined box and calibrated frequently against the standards maintained at this bureau. Two of these cells are used with the potentiometer for power measurement to guard against fortuitous changes in voltage between calibrations. Their electromotive forces, as measured and used in this work, are expressed in international volts. This international volt is defined as 1/1.0183 of the voltage of the normal Weston cell at 20° C.

The volt box ratio and the resistance of the 0.01-ohm manganin standard used in the measurements were verified at this bureau before, during, and after the experiments and showed no changes of more than 1 part in 30,000.

7. WEIGHING INSTRUMENT

The balance used in the weighings is a 2 kg Troemner balance, with a sensitivity of one scale division per milligram. Provision was made for suspending the counterpoise and the containers for water in a closed cabinet below the balance pans. All weighings are made by the method of substitution. The weights are of brass, platinum plated, and calibrated at this bureau. Correction is made for buoyancy of the air on the weights. In this method of weighing no correction for the air buoyancy on the water sample is necessary. Changes in buoyancy are compensated for by making the volume of the counterpoise approximately the same as the volume of a container. The weights are made to the nearest milligram.

8. THERMOMETRIC STANDARDS

All temperatures used in this work are measured on the international centigrade scale [7] of 1927, which is defined, in the interval 0° to 660° C., by assigning the temperatures 0°, 100°, and 444.60° C. to the ice point, steam point, and sulphur boiling point, respectively, all at the pressure of one standard atmosphere (760 mm mercury);

[7] Burgess, B. S. Jour. Research (RP22), p. 635; October, 1928.

and establishes other points by means of a standard resistance thermometer of pure platinum, making use of a formula of the form

$$R_\theta = R_o(1 + A\theta + B\theta^2)$$

in which θ is temperature, R_o the resistance at the ice point, and A and B are constants found by calibration at the steam point and the sulphur boiling point.

Before starting the calorimetric measurements the resistance thermometers were calibrated directly at the ice, steam, and sulphur points as outlined above. Later on in the work it was found expedient to calibrate the thermometers by comparison with a laboratory standard. A standard resistance thermometer of the strain-free type was inserted into a special copper receptacle which is in good thermal contact with the copper reference block in the control bath. This strain-free thermometer is calibrated at the ice, steam, and sulphur points directly, and the constants of the calorimetric spade-type thermometers are determined by direct comparison in position in the control bath. In this way it was possible by holding the bath at a constant temperature to make very accurate comparisons between the strain-free thermometer and the calorimetric thermometers. However, the strain-free thermometer was not so well adapted for indicating the temperature of the upper reference block during the calorimetric experiments, and for this reason the calorimetric thermometers were used in the actual experiments.

The thermoelements used in measuring the calorimeter temperature were calibrated in place against the resistance thermometers. The accuracy of this calibration is of little importance because of the extremely small values of the observed thermoelectromotive forces.

9. PURIFICATION OF WATER

Dissolved gases are removed from the water samples used in the experiments. In a specially designed still, ordinary distilled water is subjected to another distillation under a pressure of about 0.1 atmosphere. During this redistillation a pump is continually removing the permanent gases, together with some water vapor from the condenser, at such a rate that there is little opportunity for the permanent gases to redissolve in the condensate. In special test experiments the amount of residual gas remaining in the condensate was found to be less than one one-thousandth of the amount usually contained in distilled water. After a water sample is thus freed from dissolved gases, it is not allowed to come into contact with air again either before or during its use in the experiments, but is always kept and transferred under its own vapor pressure.

V. DESCRIPTION OF MEASUREMENTS

The keynote in the description of the experiments is that an accurate account must be kept of each of three primary observed quantities, namely, the amount of fluid subjected to the process, the change in state, and the amount of energy exchanged. The energy account consists primarily of that which is added and measured electrically, but includes also the energy added by the pump and the energy exchanged by thermal leakage. In the following discussion the method employed for the evaluation of all these factors will be described.

1. ACCOUNTING FOR MASS OF WATER

The mass of water which is subjected to a change in state enters as a direct factor in the reduction of the data. The results, therefore, can be no more reliable than the determinations of the masses. In addition, a quantitative account of the aggregate mass of the water involved in any set of experiments throws important light upon the reliability of the data derived from the experiments. Equality of the amount put into the total removed indicates that there has been no gain or loss of fluid through leaks and that there have been no accidental errors in the determination or recording of weights. In this work such a mass accounting has been carefully kept, and important revelations have resulted from it. From time to time water leaks from the calorimeter and air or oil leaks into the calorimeter have been indicated, located, and eliminated. When the mass accounts balance properly, the results assume an added degree of certainty.

The procedure employed in filling the calorimeter and in removing that water which remained after the completion of a series of experiments is the same for the α, β, and γ experiments. It will therefore be described here once for all.

A container having a reentrant tube is evacuated and filled with a charge of water from the still. The valve on the container is heated to a little above 100° C. to drive off external moisture, and the whole is cooled in a current of air, from a fan, to the temperature of the room. This treatment was found to bring the containers to a reproducible condition for weighing, and will be spoken of hereafter as conditioning.

The container and its charge of water are first weighed and then attached to the tempering coil at the bottom of the calorimeter. The calorimeter and coil are then evacuated through the vacuum valve, until a McLeod gauge in the system indicates a pressure of less than 0.001 mm. The system is then considered tight and sufficiently gas free.

The vacuum valve is then closed and the container valve opened. The water in the container is forced into the calorimeter by its own vapor pressure when heat is applied with a gas torch. Usually the entire charge is introduced, but the flow can be stopped after any chosen part has gone in if the container is suspended during the filling from one arm of a crude balance.

When the desired mass of liquid has flowed into the calorimeter, the lower calorimeter shut-off valve is closed, the tempering coil is surrounded with boiling water, and the container is immersed in cold, running water. Virtually all the water remaining in the lines is thus distilled back into the container. After a few minutes the container valve is closed and the coil is again evacuated, this time through the liquid air trap which has previously been evacuated and weighed. The vacuum valves and the valves on the trap are closed and the container and trap are detached, conditioned, and weighed. The change in weight of the container minus the weight of the water caught in the trap (always less than 1 mg, and therefore negligible when the operations are properly carried out) gives the mass of the water in the calorimeter system.

After a set of experiments in which part of the water sample may or may not have been removed, the water remaining in the calorimeter

is withdrawn into the container. This process is hastened by having the calorimeter and tempering coil hot and the container cool. When as much liquid as will flow out has been collected in the container, its valve is closed and that which remains in the calorimeter is collected in the liquid air trap. The masses thus removed are weighed as described above.

In the constant mass or α experiments the mass weighed in is equal to the mass removed if the operations have been properly performed. In the withdrawal, or β and γ, experiments the masses of water removed as saturated liquid or vapor must be included in the mass accounting.

2. HEAT-CAPACITY DETERMINATIONS

The measurements of the first type which determine the change in value of the quantity $H-L\frac{u}{u'-u}$, denoted by the symbol α, were, with a few exceptions, taken in 10° intervals. The whole range from 0° to 270° C. was divided into three sections, 0° to 100°, 100° to 200°, 200° to 270°, each of which could generally be covered in a single day's work. Starting at the lowest temperature of one of the sections, 0° C., for intsance, the initial temperature is observed. Then electric energy is added to heat the calorimeter and water approximately 10°. The temperature is again observed and energy added for another period. There is thus obtained a series of observed temperatures, between which the added energy is measured. By keeping a continuous account of the energy, including heat leak and pump energy, the change in α from the initial starting point of the series to any stopping point can be determined independently of the intermediate intervals. A single series of measurements of this kind gives as a result the amount of energy, Q, added to change the temperature of the calorimeter and contents from any one to any other of the observed temperatures. A second series carried out in a similar manner over the same intervals of temperature but with a different mass of water in the system gives as a result a second series of values of Q corresponding to these same temperature intervals. Two such series of measurements suffice to determine a series of values for the changes in α and for the changes in another quantity which is designated as Z, over the temperature intervals covered. This quantity Z, as described more fully in the paper on the analysis,[8] is a characteristic property of the calorimeter as used, and its value depends on the temperature but is independent of the total amount of water in the system. Actually, in each range of temperature several series were made in which the masses of water contained were chosen so as to give large differences in total heat capacity. Reduction of the results of such a group as a whole by the method of least squares yields a series of values of α, which is a property of saturated liquid water, and a series of values of Z, which is a property of the calorimeter as it was used. The individual values of α, corresponding to each experiment, can then be calculated for purposes of comparison to show the degree of reproducibility of the measurements of α.

In all the measurements of this type a tight-fitting cap seals the calorimeter at A in Figure 11. The water samples are introduced

[8] See footnote 2, p. 412.

and removed as liquid through the connection at the bottom of the calorimeter as previously described.

The shut-off valve in the water line is outside the boundary of the calorimeter, and so a small part of the water introduced into the system is outside the calorimeter and does not enter into the thermal process observed. This fact in no way affects the result because the method of reducing the observations eliminates it as a quantity independent of the amount of filling. Only minor differences, such, for instance, as fortuitous changes in the temperature of the small emergent portion of the water sample, could affect the results. These effects would appear as accidental errors in a large group of measurements.

The energy imparted by the pump during an experiment is taken into account in computing the results. The pump power is determined by supplementary experiments in which no electric power is supplied and heat leak is determined, as will be described presently.

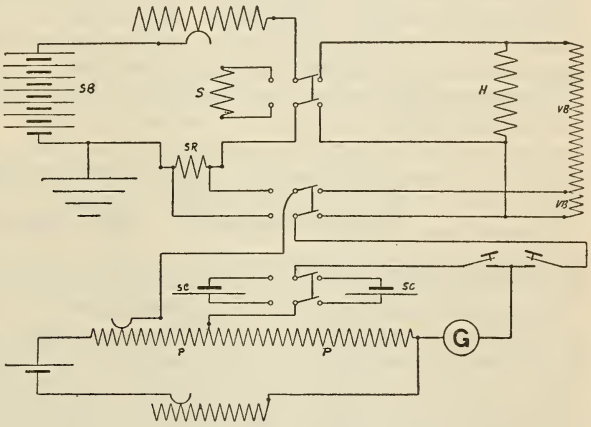


FIGURE 10.—*Wiring diagram for calorimeter heating power and its measurement*

H, calorimeter heater; *S*, spill coil; *SB*, storage battery; *SR*, standard resistance; *VB*, bolt box; *P*, potentiometer; *SC*, standard cells; *G*, galvanometer.

In the heat-capacity experiments it is not important that the pump power be known accurately. The method of reduction by combining results of experiments differing only in amount of water sample used eliminates the pump energy from the final result except for its variation from one experiment to another. Changes in this factor would enter as accidental errors in a series. Experiment showed that no systematic difference in pump power resulted from the use of different amounts of water.

The group of measurements in the range 0° to 100° C. differed from those in the other higher ranges in several respects. In the first place, it was necessary to cool the calorimeter from the laboratory temperature down to the starting point of the series as a preliminary to the experiments. At best this preliminary cooling was a slow process. On the other hand, the pressures in this range were low and the work was freer from leakage troubles incident to pressure. The measurements from 100° to 200° could be made more expeditiously, but difficulties incident to the higher temperatures and pressures were greater. Above 200° these difficulties increased, and other obstacles to operation were encountered. These resulted in a greater percentage of failures and necessitated occasional suspension of the observations for changes and repairs.

A determination of heat capacity in the range 0° to 100° will be described to illustrate the principal features of the determinations over any temperature range. The procedure is, in general, as follows:

A weighed sample of water is introduced into the calorimeter. To provide a medium for extracting heat from the calorimeter and expedite the cooling down to the initial temperature of the series, helium is introduced into the space between the calorimeter and its envelope to a pressure of about 10 cm of mercury. This gas was used because of its relatively high thermal conductivity.

Carbon dioxide is used as the refrigerating medium both for cooling the bath down and for holding it at the low temperature while the calorimeter is being cooled. During this period of cooling the calorimeter the bath is held very near, but not below 0° C. because freezing of the water in the lower tube must be avoided.

The automatic thermoregulator is used during this time to maintain a practically steady temperature of the bath. It operates by compensating the excess refrigeration with electric heating, automatically regulated in the manner previously described.

When the calorimeter has cooled to the desired temperature, the bath temperature is raised to the same value. The helium is then pumped out of the envelope space, leaving the residual pressure less than 0.001 mm of mercury. The automatic thermoregulation, the pump speed, and the power supply which is to furnish heat to the calorimeter are all finally adjusted. The mantle around the reference block is lowered, and after a short wait for a steady state to be reached the preliminaries are complete and the observations are begun.

The initial temperature of the calorimeter is measured by taking simultaneous readings on the resistance thermometers and the emf's of the five thermoelements on the calorimeter in series. Two observations on each of the three thermometers are taken for a determination of a single temperature. Readings are begun two minutes previous to the time chosen for switching on the power to the calorimeter heater and are continued at 20-second intervals until the six temperature observations have been made. The order used in reading the thermometers is not important, but was kept the same at the beginning and end of each experiment.

The operator increases the energy supply to the bath a little before switching on the power to the calorimeter heater, so that the envelope temperature and the calorimeter temperature will start to rise at nearly the same time and the same rate. On the chosen zero instant the automatic switch is thrown and the current started in the calorimeter heater. The operator, guided by indications of the differential thermoelements, keeps the power supply to the bath so adjusted that the rising temperatures of the calorimeter and envelope are kept very nearly together.

At 1-minute intervals the small temperature differences as indicated by the differential thermoelements are observed. The recorder observes the current and potential drop in the heater on alternate minutes.

The heating is continued for an integral number of minutes and stopped on the zero of that minute when the temperature is nearest to 10°. By proper preliminary adjustment of the power supply the

final temperature is brought in nearly all cases to within less than 0.1° of the chosen even temperature.

Just before the end of the heating period the operator decreases the power supply to the bath so that the bath temperature will not exceed the final temperature of the calorimeter. On the chosen instant the automatic switch is thrown and the current stopped in the calorimeter heater. As quickly as possible the bath temperature control is shifted to the thermoregulator, and a few minutes are allowed for the establishment of a steady state. During this interim, readings of the differential thermoelements are continued. Within 10 seconds after the power is turned off, the calorimeter temperature has become uniform.

When the bath temperature has become steady, the temperature of the calorimeter is observed as previously described. During the interim the power now on the spill is readjusted to take care of the change in the heat capacity of the calorimeter and its contents over the next 10° interval. This makes it possible to stop at very nearly 20° with an integral number of minutes of heating.

The final temperature of the first interval is the initial temperature of the second interval. The experiments are continued in steps of 10° as far as desired.

For temperatures of 60° and above, no refrigeration is required for the satisfactory regulation of the bath temperature.

3. LATENT-HEAT DETERMINATIONS

The measurements of the second type which determine the value of the quantity $L+L\frac{u}{u'-u}$, denoted by the symbol γ, were carried out at certain chosen temperatures at which the values of L, the heat of vaporization, were desired.

The process of evaporating and removing saturated vapor is a flow process, and in these experiments the instrument is used as a flow calorimeter with storage for the fluid sample. The experiments are carried out strictly as flow experiments proceeding at a steady state. It was possible to perform them as successive determinations, immediately following one another without disturbance of the steady condition. Sometimes as many as eight separate measurements were made in one series during a day's work.

The procedure for the measurement of latent heat is in general as as follows:

A weighed charge of water is introduced into the calorimeter. Three containers are evacuated, conditioned, weighed, and attached to the three vapor lines. The lines up to the shut-off valves are then evacuated and the vacuum valves closed.

In the following discussion the three flow lines for vapor and the corresponding shut-off valves will be designated as Nos. 1, 2, and 3. This numbering is convenient for the description of the manipulation, but has no further significance. In the preliminary operations to establish the steady state the receiver in position 1 is used, and it will be spoken of as the spill. When in use each of the tempering coils at the top is immersed in boiling water and each of the receivers in cold running water.

During the preliminary heating of the calorimeter and bath, the shut-off valve and the receiver valve in the spill line are open. This

prevents any leak past the throttle from causing pressure to build up on the diaphragm of the valves in the vapor lines. The calorimeter pump is running during the heating up and its speed is adjusted to the desired value.

When the temperature chosen for operation is reached by both the calorimeter and the bath, and when the bath temperature is properly held there by the thermoregulator, the withdrawal of vapor can be begun.

The current for the calorimeter heater, previously adjusted to the value to give the desired rate of evaporation, is then turned on. The throttle is opened and gradually adjusted to the rate of flow which will maintain the calorimeter temperature constant and equal to the practically constant temperature of the envelope. The flow into the spill in line 1 is continued for about a half hour while the operator completes the adjustment of the throttle to bring the calorimeter to a steady temperature. This much time at least was allowed to insure that any liquid which had lodged in the tubes could be swept out and a steady state of flow of dry saturated vapor established.

Meanwhile the automatic throw mechanism for the shut-off valves is adjusted so that No. 1 will close and No. 2 open at a chosen signal from the standard clock. The valve on the receiver in line No. 2 is opened to allow passage of vapor when shut-off valve No. 2 opens.

Before starting the measurements, a survey of the temperature existing at various points in the system is made to verify the existence of the steady state.

Six temperature observations are taken at times 10, 20, and 30 seconds before and after the transfer of the flow from line 1 to line 2. For these observations simultaneous readings are taken of the resistance of a single thermometer and the emf of the five thermoelements on the calorimeter in series.

On the chosen minute the flow is shifted from line 1 to line 2. Observations of the temperatures of the calorimeter and reference block are made on each succeeding minute, the operator maintaining the calorimeter temperature as nearly constant as possible by adjustment of the throttle valve. Observations are made of current and potential drop in the calorimeter heater on the alternate minutes. Meanwhile determinations are made of the mass of water which has been removed, by weighing the spill and the residual water in the lines which has been caught in the liquid air trap. A weighed receiver is put in position 1 and the tempering coil evacuated. The valve mechanism is reset to be ready for the transfer of the flow from line 2 to line 3.

Water samples removed are usually about 30 g. The time of an experiment is therefore determined by the rate at which the energy is supplied to the calorimeter. After the desired amount of water has been collected in position 2, temperatures are again measured as before.

The above-described procedure is repeated as long as time or the quantity of water in the calorimeter permits, each experiment constituting an independent determination.

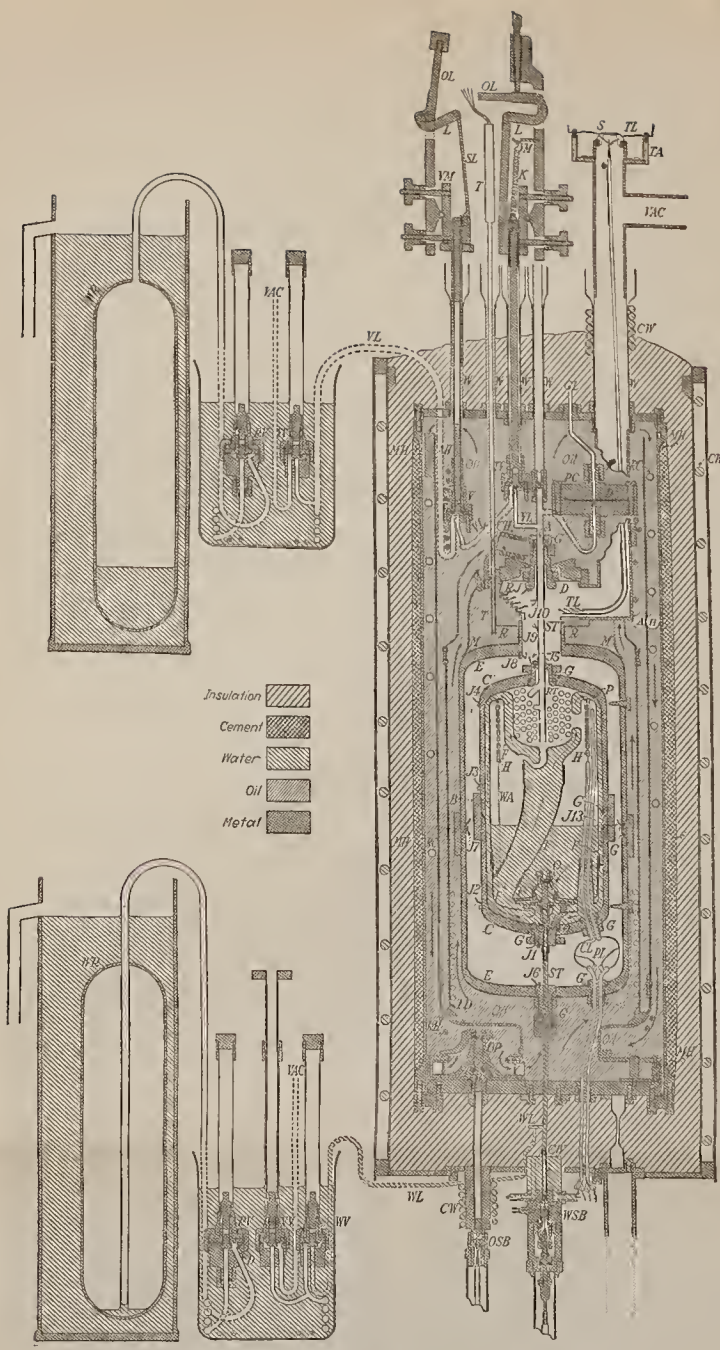


FIGURE 11.—*Section of assembled calorimeter*

(NOTE.—This is not a true section but shows sections of important parts projected on a plane)

C, calorimeter shell (Cu-Ni).
E, envelope shell (Cu-Ni).
B, threaded band (Monel).
G, gold gaskets.
ST, support tubes (Ag-Pd) (water and steam outlets).
I, pump impeller.
F, pump casing (Ag).
O, ball bearings (Ir alloy).
P, water port.
H, calorimeter heater (Ag).
WA, gauze apron (Ag).
CL, current lead (Au).
PL, potential lead (Au).
PC, pressure capsule (Monel)
GL, gage line.
WL, liquid water line (Ag).
WSB, water stuffing box.
WV, water valve.
WR, water receiver.
RV, receiver valve.
VAC, vacuum line.
VV, vacuum valve.
VL, vapor line.
V, shut-off valve.
TV, throttle valve.
VM, valve mechanism.
OL, operating lever.
SL, spring lever.
L, link.
K, backlash spring.
TD, thermoregulator dilatometer.
R, reference block (Cu).
D, diaphragm.
M, mantle.
J1, *J2*, * * *, principal junctions.
RJ, reference junctions.
TL, thermoelement leads (Au).
S, gas-tight insulating seal.
TA, anchorage for *TL* leads (Cu).
T, Pt resistance thermometer.
OIL, oil bath.
OP, oil pump.
OSB, oil stuffing box.
MH, main heater.
AH, auxiliary heater.
RH, regulating heater.
CH, central heater.
RC, refrigerating coil.
CW, cooling water.

4. EVAPORATION FACTOR

The α experiments yield values of the quantity $H-L\frac{u}{u'-u}$ and the γ experiments yield values of $L+L\frac{u}{u'-u}$. To determine the values of H and L from these quantities it is necessary to know the value of the quantity $L\frac{u}{u'-u}$, which has been designated as β. In the analysis [9] it is shown that this correction term β may be determined calorimetrically as the amount of energy which is supplied per gram of saturated liquid withdrawn at a constant temperature.

The procedure for a determination of β at a given temperature is as follows:

A weighed charge of water is introduced into the calorimeter. The temperatures of the calorimeter and the bath are brought to the value chosen for operation. The electric power on the spill is adjusted so that the proper rate of withdrawal of water will approximate a chosen value. The pump speed is adjusted and controlled as in the α and γ experiments.

A weighed container is attached to the lower tempering coil and the coil evacuated. The shut-off valve in the liquid line is now of the throttling type previously described, with arrangements for control by the operator at the instrument table.

The temperature of the calorimeter is measured as in the α experiments, and the power is similarly thrown on. As quickly as possible the operator opens the throttle for the liquid and adjusts it until the temperature of the calorimeter is constant and practically equal to the bath temperature. As in the α experiments, readings of the differential thermoelements and the power to the heater are recorded at the successive 1-minute intervals. At the chosen instant for stopping the experiment the power is cut off. The throttle is closed at such a time that the final temperature of the calorimeter is nearly the same as that of the bath. If the calorimeter is a little too hot, more liquid can be withdrawn until the desired state is reached. The final temperature is then measured as before. The water withdrawn is collected and weighed in the manner already described.

No provision was made for making more than a single β experiment at a time, and therefore it was necessary to measure only the time of electric heating and not the time of flow.

5. THERMAL LEAKAGE

When a difference of temperature exists between the calorimeter and its envelope, there is an accompanying transfer of heat by radiation, conduction, and convection. For small temperature differences the amount of energy transferred per unit time is proportional to this temperature difference.

In operation it is impossible to keep the temperatures of the calorimeter and its envelope identical at all times. The existing temperature difference can, however, be kept very small, and over a period of time can be so controlled that the integrated value is almost zero. In the measurements this ideal was approached as the operator gained experience.

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[9] See footnote 2, p. 412.

To properly correct for the thermal leakage in those experiments where the temperature difference did not integrate to zero, a set of experiments was performed to determine the thermal-leakage coefficient. These experiments are performed under temperature conditions which are identical, as far as is possible, with those prevailing during the α, β, and γ experiments, except that the temperature difference between the calorimeter and its envelope is purposely much greater. The total amount of energy transferred under this exaggerated temperature difference, the value of the difference, and the time over which the difference exists are observed. No electrical energy is added to the calorimeter, and during most of the time of an experiment the pump is stopped. Thus practically all of the observed energy change is due to thermal leakage. Because the calorimeter was used both with the envelope space evacuated and filled with nitrogen, a set of heat-leak experiments under each of these conditions was necessary. These heat-leak experiments are carried out as follows:

The calorimeter is charged with about 250 g of water and its temperature and that of the bath are brought to the temperature chosen for operation. The initial temperature is observed with the pump running, and on the next minute the pump is stopped. The temperature of the bath is then raised or lowered until the envelope is either hotter or colder than the calorimeter by an amount corresponding to about 100 microvolts (two-thirds of a degree) on the differential or regulating thermoelements. At 1-minute intervals readings of this indication are recorded in microvolts over a period of from 30 minutes to one hour. At the end of this time the bath temperature is brought back to that of the calorimeter and on an integral minute the pump is started to insure uniformity of temperature throughout the calorimeter. The final temperature is then observed as before.

The pump is stopped during most of the time of the experiment so that the uncertainty in the determination of the energy supplied by the pump does not enter into the determination of the thermal-leakage rate. Small corrections are made for the energy supplied by the pump during the short intervals at the beginning and end of the experiment.

The data obtained in such an experiment, when combined with the previously determined heat capacity of the calorimeter and its contents, yield the amount of heat transferred per microvolt-minute, at the temperature of the experiment. In accordance with Newton's law of cooling, this coefficient or thermal-leakage rate can be used as a factor which, when multiplied by the resultant number of microvolt-minutes for any experiment at that temperature, gives directly the net heat exchange due to heat leak. At the higher temperatures, where a small difference in temperature corresponds to a much larger difference in vapor pressure, the bath was kept colder than the calorimeter in the heat-leak experiments. This insured against the direct transfer of heat from the bath to the calorimeter by active boiling in the lower support tube.

The heat-leak experiments, on account of the method in which they are performed, furnish an opportunity for the direct calibration of the thermoelements against the resistance thermometers. If the bath temperature is measured both before and after it is changed,

simultaneous indications of the five thermoelements on the calorimeter in series can be interpreted directly in terms of the thermometers, since the change in the calorimeter temperature in the short interval of time involved is small. Only the five series thermoelements were so calibrated, because the indications of the others need not be expressed in degrees.

6. PUMP ENERGY

The energy supplied to the calorimeter by the pump appears as a correction which must be applied to obtain the total energy added in the α, β and γ experiments. As previously shown, the knowledge of the true value of this pump energy is not of vital importance in the determinations of α, but it appears directly in the evaluation of β and γ, and must therefore be carefully determined.

The pump energy determinations are carried out as follows:

The calorimeter, containing a known mass of water, is brought, along with the bath, to the temperature chosen for the observation. The pump speed is regulated to the desired value. The initial temperature of the calorimeter is measured at a chosen time. At 1-minute intervals the indications of the differential thermoelements are recorded. The bath temperature is raised from time to time to reduce the integrated value of the temperature difference between calorimeter and envelope to virtually zero. After a period varying from 30 minutes to one hour the final temperature of the calorimeter is observed.

The data obtained from such an experiment, together with the previously determined heat capacity of the calorimeter and its contents, yield directly the rate at which energy is supplied to the calorimeter by the pump.

Similar experiments carried out with different quantities of water in the calorimeter showed no systematic variation in the pump energy rate with the mass of the water.

Experiments were performed with the pump running at various speeds, but throughout most of the work the speed employed was about 900 revolutions per minute.

VI. RESULTS OF MEASUREMENTS

1. ALPHA EXPERIMENTS

In the following record of the results of the measurements the experimental data have been assembled in the form of tables. An example of the record of a single determination of heat capacity of the calorimeter and its charge of water, over a 10° interval, is given in Table 1. The total time of experiment over which the heat-leak and pump-energy corrections are applied is the interval between the middle instants of the initial and final periods of temperature readings. The total heat-leak factor for this interval is the sum of the heat-leak indications at 1-minute periods during this time. This factor in microvolt-minutes multiplied by the heat-leak coefficient in joules per microvolt-minute gives the heat-leak correction in joules. Numerous determinations of the heat-leak coefficient were made, and the values observed have been assembled in the form of a chart. (Fig. 12.)

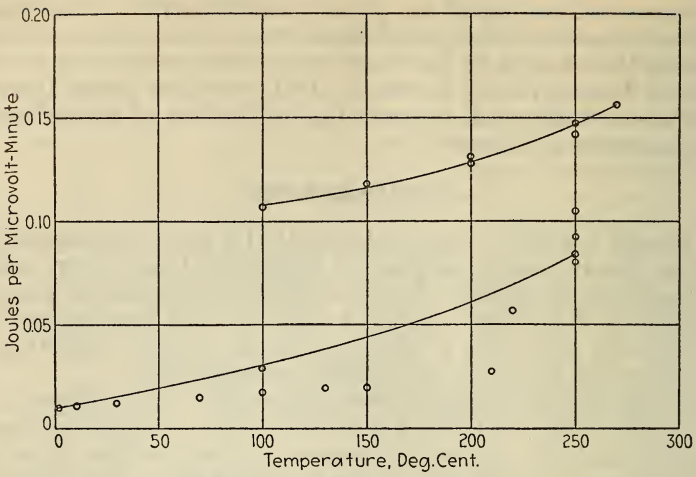

FIGURE 12.—*Heat-leak coefficient*

Lower curve with space evacuated; upper curve with nitrogen in space.

TABLE 1.—*Data sheet—Determination of heat capacity*

Experiment No. 193-U. January 26, 1929.

200° to 210° C.

Observers: N. S. O., H. F. S., and E. F. F.

Time	Thermometers		Thermo-elements		Electric power	
	Designation	Bridge	t. e. 1-5	Regulating	I	E
		Ohms	*μv.*	*μv.*	*Amperes*	*Volts*
12.21.00	2 *n*	45. 2890	9. 0	2		
12.21.20	2 *r*	45. 2939	8. 8			
12.21.40	3 *r*	45. 4794	8. 8			
12.22.00	3 *n*	45. 4735	8. 5			
12.22.20	4 *n*	45. 8176	8. 6			
12.22	4 *r*	45. 8143	8. 7			
12.23				3		On.
12.24				0	1. 9929	
12.25				2		20. 195
12.26				2	1. 9924	
12.27				1		20. 195
12.28				−2	1. 9920	
12.29				2		20. 193
12.30				−5	1. 9916	
12.31				−3		20. 192
12.32				−1	1. 9912	
12.33				0		20. 193
12.34				−3	1. 9909	
12.35				−2		Off 20. 192
12.36				3		
12.37				2		
12.38				2		
12.39.00	2 *n*	46. 2525	7. 1			
12.39.20	2 *r*	46. 2581	7. 2			
12.39.40	3 *r*	46. 4470	7. 2			
12.40.00	3 *n*	46. 4402	7. 1			
12.40.20	4 *n*	46. 7902	6. 8			
12.40.40	4 *r*	46. 7858	6. 8			

Total heat-leak factor = +5 μv minutes. Total time of experiment 12.22 to 12.40=1,080 seconds. Total time of electric heating, 12.23 to 12.35=720 seconds.

The correction for pump energy is computed as the product of the total time of the experiment by the pump power. The values of the pump power taken were those determined from time to time in special

blank experiments for obtaining this quantity. Nearly 200 pump-energy determinations were made throughout the experimental work, and the values observed have been assembled in the form of a chart. (Fig. 13.) In computing the results of the work on heat capacity the values for pump power have been modified at various times in the light of additional determinations. It has not been necessary to revise the earlier calculations on the basis of a uniform value for pump power, because this factor has so little effect on the final result.

A partial reduction of the observations is given in Table 2. This includes the computation of the initial and final temperatures of the calorimeter and the computation of the electric energy added. The indication of each of the three platinum resistance thermometers is

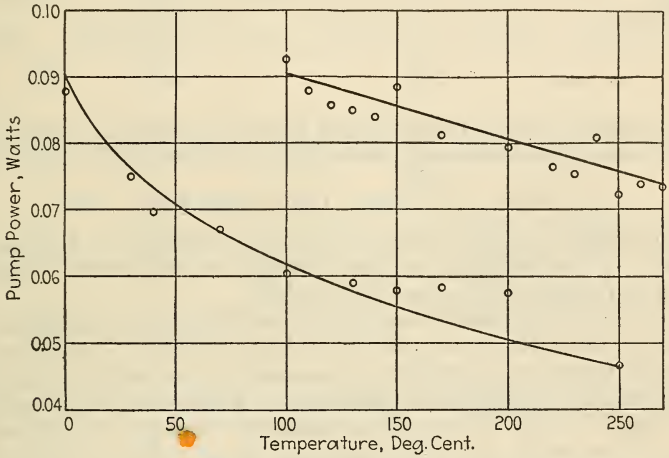

FIGURE 13.—*Pump power*

Lower curve with tachometer at 51 cm; upper curve with tachometer at 70 cm.

computed separately. The mean of the three is then taken as the temperature of the reference block. The mean of the six readings of the five series thermoelements on the calorimeter, reduced to degrees, gives the difference in temperature between the reference block and the calorimeter. The observed temperature of the reference block minus this difference equals the calorimeter temperature at the middle instant of the series of temperature observations.

TABLE 2.—*Computation—determination of heat capacity*

Experiment No. 193-U. 200° to 210° C.

	Initial			Final		
Thermometer No.	2	3	4	2	3	4
$(n+r)/2$	45.2914	45.4764	45.8159	46.2553	46.4436	46.7880
Bridge correction	.0096	.0096	.0096	.0096	.0096	.0096
R_θ	45.3010	45.4860	45.8255	46.2649	46.4532	46.7976
$R_\theta - R_0$	19.6930	19.7575	19.8716	20.6569	20.7247	20.8437
$100\ (R_\theta - R_0)/(R_{100} - R_0)$	197.090	197.095	197.064	206.737	206.744	206.704
$0.01\ \theta\ (0.01\ \theta - 1)\ \delta$	2.961	2.965	2.997	3.425	3.429	3.466
Reference block temperature	200.051	200.060	200.061	210.162	210.173	210.170
Mean reference block temperature	----------	200.057	----------	----------	210.168	----------
Mean t. e. 1–5 (microvolts)	8.73	----------	----------	7.03	----------	----------
Mean t. e. 1–5 (degrees)	----------	−.030	----------	----------	−.024	----------
Temperature of calorimeter	----------	200.027	----------	----------	210.144	----------

Calculation of energy

Potentiometer	Current (amperes)		Voltage
Mean reading	1.99183	Mean reading	20.1933
Pot. correction	.00020	Pot. correction	.0020
Correction for std. 0.01 ohm	−.00010	Correction for volt-box factor	.0067
Correction for volt-box current	−.00060		
Current I=	1.99133	Voltage E=	20.2020

Time of electric heating=t=	seconds	720	
Total electric energy=IEt=	joules		28,964.8
Total time of experiment	seconds	1,080	
Pump power	watts	.0759	
Pump energy			82.0
Total heat-leak factor	mv-min	5	
Heat-leak coefficient	joules/mv-min	.129	
Heat leak			.6
Entire energy added	joules		29,047.4

The computation of temperature from the observed resistance of the platinum thermometers is made by use of the Callendar formula—

$$\theta = 100(R_\theta - R_0)/(R_{100} - R_0) + 0.01\theta(0.01\theta - 1)\delta.$$

The constants R_0, $R_{100} - R_0$, and δ are determined, as previously described, by calibration either directly or indirectly, using ice, steam, and boiling sulphur as fixed points.

In computing the electric energy, corrections are applied for potentiometer calibration, standard 0.01-ohm resistance, volt-box ratio, and for the fraction of the total measured current which is carried by the volt box as a shunt across the heater. These corrections are added to the mean values of the potentiometer readings for current and voltage. The product of the corrected mean values of current and voltage, multiplied by the number of seconds of electric heating, gives the total energy added electrically. An approximation is involved in taking the means of the readings before taking the products, but in all these experiments the power was so nearly constant that even in the extreme case this is less than 1 part in 100,000 and therefore negligible.

The principal data from the entire group of experiments of this type are given in Table 3. These experiments are arranged in groups, each of which includes all those covering a certain temperature interval. The masses given are corrected to the nearest milligram for error in the weights. These masses are the amounts of water introduced into the system, including the portion filling the water line out to the shut-off valve. The initial and final temperatures and total electric energy are computed as described above.

TABLE 3.—*Principal data from α experiments* $Q]_1^2 = M\alpha]_1^2 + Z]_1^2$. $\alpha]_1^2 = \left[H - L\frac{u}{u'-u}\right]_1^2$

Experiment No.	Date	Mass of water M	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Time of electric heating	Total electric energy	Pump energy	Heat leak	Entire energy added Q	Energy for even temperature intervals $Q]_1^2$	$\alpha]_1^2$	Residual $\alpha]_1^2 - \alpha_m$
		g	°*C.*	°*C.*	*Seconds*	*Seconds*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules/g*	*Int. joules/g*
35-A	June 10, 1927	487.107	1.402	10.285	1,320	540	25,427.3	116.4	2.6	25,546.2	28,769.8	41.982	−0.001
36-A	June 13, 1927	487.107	1.546	10.380	1,440	540	25,277.6	127.0	1.9	25,406.5	28,772.8	41.988	.005
37-A	June 16, 1927	487.107	1.504	10.273	2,580	1,020	24,981.5	228.0	3.2	25,212.8	28,763.2	41.968	−.015
42-A	July 11, 1927	326.833	1.627	8.987	1,380	480	16,091.9	120.6	1.6	16,214.1	22,032.0	41.953	−.030
45-A	July 14, 1927	326.833	2.508	9.209	1,380	420	14,645.2	119.8	1.5	14,766.5	22,039.0	41.975	−.008
46-A	July 16, 1927	326.833	1.323	9.265	1,380	480	17,374.3	120.0	1.6	17,495.7	22,033.8	41.959	−.024
49-A	July 22, 1927	493.054	1.602	9.818	1,320	480	23,727.8	116.1	1.3	23,845.2	29,033.6	42.010	.027
51-A	July 25, 1927	493.054	1.716	10.260	1,440	480	24,661.7	125.0	1.9	24,788.6	29,026.6	41.996	.012
57-A	Aug. 2, 1927	291.001	1.196	9.499	2,820	1,080	16,818.1	246.7	2.1	17,066.9	20,555.7	42.046	.063
58-A	Aug. 3, 1927	291.001	1.021	9.802	2,760	1,080	17,795.3	240.2	2.5	18,038.1	20,543.6	42.005	.022
59-A	Aug. 4, 1927	291.001	.908	9.880	2,580	1,080	18,204.3	225.4	3.5	18,433.2	20,546.7	42.015	.032
62-A	Aug. 9, 1927	366.801	.552	10.100	3,420	[1] 1,260	22,340.6	297.7	2.3	22,640.6	23,710.6	41.958	−.025
63-A	Aug. 10, 1927	366.801	1.029	10.083	2,340	[1] 1,080	21,256.0	203.3	1.6	21,460.9	23,702.8	41.937	−.046
Even-temperature interval 0°–10°. $Z]_0^{10} = 8{,}320.3$ Int. joules. Mean value of $\alpha]_0^{10} = \alpha_m = 41.9832$ Int. joules per g.													
35-B	June 10, 1927	487.107	10.284	20.210	1,500	598	28,394.3	120.5	3.8	28,518.6	28,731.0	41.799	−.003
36-B	June 13, 1927	487.107	10.380	20.447	1,440	600	28,808.9	115.7	1.8	28,926.3	28,732.6	41.802	.000
37-B	June 16, 1927	487.107	10.273	20.192	2,760	1,200	28,273.1	220.6	4.6	28,498.2	29,732.2	41.802	.000
38-B	June 17, 1927	487.107	9.955	19.653	2,940	1,200	27,628.9	236.2	3.3	27,868.5	28,736.1	41.810	.008
39-B	June 20, 1927	487.107	9.995	19.824	3,240	1,200	27,981.0	260.8	3.8	28,245.5	28,736.7	41.811	.009
42-B	July 11, 1927	326.833	9.136	20.203	1,740	660	24,235.8	140.2	1.6	24,377.6	22,025.8	41.781	−.021
46-B	July 16, 1927	326.833	9.265	19.212	1,440	600	21,788.4	116.0	1.6	21,906.0	22,024.7	41.778	−.024
49-B	July 22, 1927	493.054	9.817	20.445	1,560	660	30,677.7	124.4	1.7	30,803.8	28,979.0	41.798	−.004
51-B	July 25, 1927	493.054	10.259	19.688	1,620	600	27,193.5	127.9	3.1	27,324.5	28,980.9	41.802	.000
57-B	Aug. 2, 1927	291.001	9.500	19.147	1,500	600	19,691.1	120.2	1.3	19,812.6	20,538.7	41.816	.014
58-B	Aug. 3, 1927	291.001	9.802	19.923	1,920	600	20,637.9	153.9	1.0	20,792.8	20,542.2	41.828	.026
59-B	Aug. 4, 1927	291.001	9.879	20.015	1,440	600	20,703.7	113.8	1.7	20,819.2	20,539.5	41.818	.016
62-B	Aug. 9, 1927	366.801	10.100	20.625	1,620	[1] 780	24,818.4	129.0	1.0	24,948.4	23,699.9	41.793	−.009
63-B	Aug. 10, 1927	366.801	10.083	20.001	1,200	[1] 600	23,409.1	95.2	1.4	23,505.7	23,699.3	41.791	−.011
Even-temperature interval 10°–20°. $Z]_{10}^{20} = 8{,}370.5$ Int. joules. Mean value of $\alpha]_{10}^{20} = \alpha_m = 41.8016$ Int. joules per g.													

[1] Times were determined with a sidereal chronometer, and must be multiplied by 0.99735 to obtain mean solar seconds.

TABLE 3.—*Principal data from α experiments* $Q]_1^2 = M\alpha]_1^2 + Z]_1^2$. $\alpha]_1^2 = \left[H - L\frac{u}{u'-u}\right]_1^2$—Continued

Experiment No.	Date	Mass of water M	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Time of electric heating	Total electric energy	Pump energy	Heat leak	Entire energy added Q	Energy for even temperature intervals $Q]_1^2$	$\alpha]_1^2$	Residual $\alpha]_1^2 - \alpha_m$
		g	°*C.*	°*C.*	*Seconds*	*Seconds*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules/g*	*Int. joules/g*
35-C	June 10, 1927	487.107	20.210	30.208	1,620	600	28,626.1	120.4	3.4	28,749.9	28,754.2	41.713	0.005
36-C	June 13, 1927	487.107	20.447	30.364	1,380	600	28,407.4	102.6	2.0	28,511.9	28,749.9	41.704	−.004
37-C	June 16, 1927	487.107	20.191	30.142	1,500	600	28,493.8	111.2	2.7	28,607.9	28,748.8	41.702	−.006
43-C	July 12, 1927	326.833	20.034	29.581	1,500	600	20,948.8	112.0	2.2	21,062.9	22,061.9	41.692	−.016
46-C	July 16, 1927	326.833	19.212	29.458	1,740	600	22,464.4	130.0	3.8	22,598.2	22,057.9	41.680	−.028
49-C	July 22, 1927	493.054	20.445	30.088	1,440	600	27,859.5	105.7	2.6	27,967.8	29,005.8	41.720	.012
51-C	July 25, 1927	493.054	19.688	29.507	1,380	600	28,368.2	101.7	2.8	28,472.7	28,998.2	41.705	−.003
53-C	July 27, 1927	493.054	19.809	29.487	1,800	600	27,929.1	131.9	3.2	28,064.2	29,002.7	41.714	.006
57-C	Aug. 2, 1927	291.001	19.147	29.899	1,380	660	22,014.6	103.0	1.4	22,119.0	20,572.5	41.707	−.001
58-C	Aug. 3, 1927	291.001	19.923	29.984	1,380	600	20,597.4	102.6	2.1	20,702.1	20,576.8	41.722	.014
59-C	Aug. 4, 1927	291.001	20.015	30.114	1,440	600	20,680.3	106.5	2.0	20,788.8	20,583.8	41.746	.038
62-C	Aug. 9, 1927	366.801	20.625	28.802	1,380	[1] 540	19,299.1	102.8	1.4	19,403.3	23,732.4	41.703	−.005
63-C	Aug. 10, 1927	366.801	20.001	29.889	1,200	[1] 600	23,376.3	88.9	1.4	23,466.6	23,731.4	41.700	−.008
Even-temperature interval 20°–30°. $Z]_{20}^{30} = 8{,}435.7$ Int. joules. Mean value of $\alpha]_{20}^{30} = \alpha_m = 41.7078$ Int. joules per g.													
35-D	June 10, 1927	487.107	30.209	40.169	1,380	600	28,580.2	97.3	3.1	28,680.6	28,973.7	41.703	.000
36-D	June 13, 1927	487.107	30.364	40.268	1,560	600	28,401.2	110.0	3.8	28,515.0	28,791.7	41.699	−.004
37-D	June 16, 1927	487.107	30.142	40.118	1,560	600	28,613.4	110.0	3.0	28,726.4	28,794.6	41.705	.002
43-D	July 12, 1927	326.833	29.850	39.633	1,560	600	21,507.6	109.7	1.7	21,619.0	22,100.6	41.675	−.028
46-D	July 16, 1927	326.833	29.458	39.576	1,380	600	22,263.8	96.5	1.4	22,361.7	22,103.6	41.684	−.019
49-D	July 22, 1927	493.054	30.089	39.914	1,380	600	28,440.1	96.8	2.3	28,539.2	29,047.4	41.715	.012
51-D	July 25, 1927	493.054	29.507	39.689	1,380	600	29,470.7	97.0	2.5	29,570.2	29,043.4	41.706	.003
53-D	July 27, 1927	493.054	29.487	39.523	1,500	600	29,037.4	105.5	3.4	29,146.3	29,044.9	41.709	.006
57-D	Aug. 2, 1927	291.001	29.899	40.553	1,380	600	21,868.9	96.7	1.7	21,967.3	20,616.8	41.707	.004
58-D	Aug. 3, 1927	291.001	29.984	40.000	1,140	600	20,571.9	79.9	1.9	20,653.7	20,619.7	41.717	.014
59-D	Aug. 4, 1927	291.001	30.114	40.002	1,200	600	20,316.1	83.8	1.3	20,401.2	20,632.5	41.761	.058
62-D	Aug. 9, 1927	366.801	28.802	40.356	1,380	[1] 780	27,368.1	96.7	1.6	27,466.4	23,774.0	41.696	−.007
63-D	Aug. 10, 1927	366.801	29.889	39.922	1,140	[1] 600	23,772.2	79.8	1.6	23,853.6	23,765.2	41.672	−.031
Even-temperature interval 30°–40°. $Z]_{30}^{40} = 8{,}480.0$ Int. joules. Mean value of $\alpha]_{30}^{40} = \alpha_m = 41.7032$ Int. joules per g.													

35-E	June 10, 1927	487.107	40.169	50.095	1,320	600	28,541.7	89.9	2.5	28,634.1	28,846.0	41.708	.010
36-E	June 13, 1927	487.107	40.268	50.136	1,320	600	28,374.2	89.9	2.5	28,466.5	28,844.4	41.705	.007
37-E	June 16, 1927	487.107	40.118	50.072	1,380	600	28,607.7	93.9	2.8	28,704.4	28,837.7	41.691	−.007
43-E	July 12, 1927	326.833	39.633	49.965	1,560	600	22,782.0	104.4	3.0	22,889.4	22,153.5	41.685	−.013
49-E	July 22, 1927	493.054	39.914	49.861	1,440	600	28,830.6	97.3	1.7	28,929.6	29,084.1	41.688	−.010
51-E	July 25, 1927	493.054	39.689	50.055	1,440	600	30,055.0	97.5	2.2	30,154.7	29,093.6	41.707	.009
53-E	July 27, 1927	493.054	40.084	50.072	1,380	600	28,958.3	93.5	2.1	29,053.9	29,089.2	41.699	.001
57-E	Aug. 2, 1927	291.001	40.553	50.097	1,260	540	19,642.6	84.5	2.6	19,729.1	20,667.0	41.709	.011
58-E	Aug. 3, 1927	291.001	40.001	50.159	1,140	600	20,910.0	76.4	1.9	20,988.3	20,660.6	41.687	−.011
59-E	Aug. 4, 1927	291.001	40.002	49.867	1,440	600	20,296.6	96.1	2.1	20,394.8	20,673.2	41.730	.032
62-E	Aug. 9, 1927	366.801	40.356	50.450	1,200	[1] 660	23,932.6	80.1	1.0	24,013.7	23,821.9	41.691	−.007
63-E	Aug. 10, 1927	366.801	39.922	50.111	1,200	[1] 600	24,186.9	80.1	2.1	24,269.1	23,818.3	41.681	−.017

Even-temperature interval 40°–50°. $Z]_{40}^{50}=8{,}529.7$ Int. joules. Mean value of $\alpha]_{40}^{50}=\alpha_m=41.6981$ Int. joules per g.

35-F	June 10, 1927	487.107	50.095	59.991	1,440	600	28,503.5	95.1	3.6	28,602.3	28,903.7	41.685	.002
36-F	June 13, 1927	487.107	50.136	60.052	1,560	600	28,549.3	103.1	4.5	28,656.9	28,900.0	41.677	−.006
37-F	June 16, 1927	487.107	50.072	60.070	1,440	600	28,804.7	95.0	3.6	28,903.3	28,909.3	41.696	.013
44-F	July 13, 1927	326.833	49.962	60.055	1,440	600	22,322.4	93.7	2.0	22,418.1	22,210.1	41.647	−.036
49-F	July 22, 1927	493.054	49.861	59.995	1,500	600	29,446.5	98.7	2.7	29,547.9	29,158.3	41.695	.012
51-F	July 25, 1927	493.054	50.055	60.173	1,500	600	29,391.5	98.7	3.1	29,493.3	29,147.2	41.676	−.007
53-F	July 27, 1927	493.054	50.072	59.908	1,380	600	28,574.7	90.7	3.4	28,668.8	29,148.7	41.679	−.004
57-F	Aug. 2, 1927	291.001	50.097	60.100	1,380	600	20,647.1	88.8	1.9	20,737.8	20,740.0	41.722	.039
58-F	Aug. 3, 1927	291.001	50.159	60.096	1,200	600	20,521.2	77.2	2.8	20,601.2	20,727.9	41.681	−.002
59-F	Aug. 4, 1927	291.001	49.867	59.855	1,380	600	20,618.1	88.6	2.8	20,709.5	20,734.2	41.703	.020
62-F	Aug. 9, 1927	366.801	50.450	59.584	1,320	[1] 600	21,731.3	84.9	1.0	21,817.2	23,884.6	41.673	−.010
63-F	Aug. 10, 1927	366.801	50.111	60.264	1,500	[1] 600	24,150.1	96.2	1.1	24,247.4	23,880.7	41.663	−.002

Even-temperature interval 50°–60°. $Z]_{50}^{60}=8{,}598.6$ Int. joules. Mean value of $\alpha]_{50}^{60}=\alpha_m=41.6833$ Int. joules per g.

35-G	June 10, 1927	487.107	59.991	69.962	1,260	600	28,798.7	81.0	2.9	28,882.6	28,967.7	41.690	.007
36-G	June 13, 1927	487.107	60.052	69.997	1,380	600	28,714.6	88.7	3.8	28,807.2	28,965.1	41.685	.002
47-G	June 16, 1927	487.107	60.070	70.096	1,680	600	28,921.8	107.8	4.2	29,033.9	28,958.9	41.672	−.011
34-G	July 13, 1927	326.833	60.055	70.368	1,560	600	22,887.6	97.8	2.2	22,987.6	22,278.1	41.666	−.017
49-G	July 22, 1927	493.054	59.995	70.327	1,380	600	30,094.3	88.3	1.7	30,134.3	29,214.1	41.687	.004
50-G	July 23, 1927	493.054	59.997	70.202	1,500	600	29,714.9	96.0	2.6	29,813.5	29,212.5	41.685	.002
51-G	July 25, 1927	493.054	60.173	70.093	1,440	600	28,888.6	90.8	2.2	28,981.6	29,212.3	41.685	.002
52-G	July 26, 1927	493.054	60.156	70.048	2,040	600	28,768.7	130.1	2.4	28,901.2	29,215.7	41.690	.007
53-G	July 27, 1927	493.054	59.908	69.821	1,350	600	28,869.6	86.4	2.0	28,958.0	29,209.0	41.677	−.006
57-G	Aug. 2, 1927	291.001	60.100	70.061	1,320	600	20,629.8	82.9	2.2	20,714.9	20,787.0	41.673	−.010
58-G	Aug. 3, 1927	291.001	60.096	69.990	1,140	600	20,498.6	71.5	1.6	20,571.7	20,791.6	41.689	.006
59-G	Aug. 4, 1927	291.001	59.855	70.135	1,260	600	21,299.2	78.9	1.5	21,379.7	20,798.2	41.711	.028
62-G	Aug. 9, 1927	366.801	59.584	69.592	1,380	[1] 660	23,875.1	86.4	2.0	23,963.5	23,947.5	41.678	−.005
63-G	Aug. 10, 1927	366.801	60.264	70.195	1,140	[1] 600	23,711.2	71.5	1.3	23,949.7	23,947.4	41.677	−.006

Even-temperature interval 60°–70°. $Z]_{60}^{70}=8{,}660.2$ Int. joules. Mean value of $\alpha]_{60}^{70}=\alpha_m=41.6828$ Int. joules per g.

[1] See footnote 1, p. 445.

TABLE 3.—*Principal data from α experiments* $Q]_1^2 = M\alpha]_1^2 + Z]_1^2$. $\alpha]_1^2 = \left[H - L\frac{u}{u'-u}\right]_1^2$—Continued

Experiment No.	Date	Mass of water M	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Time of electric heating	Total electric energy	Pump energy	Heat leak	Entire energy added Q	Energy for even temperature intervals $Q]_1^2$	$\alpha]_1^2$	Residual $\alpha]_1^2 - \alpha_m$
		g	°*C.*	°*C.*	*Seconds*	*Seconds*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules/g*	*Int. joules/g*
35-H	June 10, 1927	487.107	69.962	80.078	1,320	600	29,281.6	82.6	3.2	29,367.4	29,030.1	41.677	−0.008
36-H	June 13, 1927	487.107	69.997	80.439	1,560	600	29,071.5	97.6	4.2	29,173.3	29,037.9	41.693	.008
37-H	June 16, 1927	487.107	70.096	80.201	1,440	600	29,248.8	90.0	3.2	29,342.0	29,034.0	41.685	.000
44-H	July 13, 1927	326.833	70.474	80.725	1,500	600	22,816.3	91.5	2.5	22,910.2	22,342.4	41.653	−.032
49-H	July 22, 1927	493.054	70.327	80.621	1,440	600	30,059.6	89.6	4.3	30,153.5	29,285.6	41.693	.008
50-H	July 23, 1927	493.054	70.202	80.363	1,440	600	29,665.7	89.8	1.9	29,757.4	29,280.5	41.683	−.002
52-H	July 26, 1927	493.054	70.048	79.885	1,440	600	28,717.5	89.7	2.0	28,809.2	29,281.0	41.684	−.001
53-H	July 27, 1927	493.054	69.821	80.169	1,350	600	30,216.3	84.3	1.8	30,302.4	29,282.3	41.686	.001
57-H	Aug. 2, 1927	291.001	70.061	79.982	1,380	600	20,610.7	84.4	1.9	20,697.0	20,861.5	41.693	.008
58-H	Aug. 3, 1927	291.001	69.990	80.016	1,260	600	20,834.2	77.0	1.7	20,912.9	20,858.0	41.681	−.004
59-H	Aug. 4, 1927	291.001	70.135	80.218	1,440	600	20,955.7	87.9	3.1	21,046.7	20,869.7	41.721	.036
62-H	Aug. 9, 1927	366.801	69.592	80.268	1,260	[1] 600	25,561.6	77.0	1.4	25,640.0	24,016.4	41.678	−.007
63-H	Aug. 10, 1927	366.801	70.195	80.087	1,140	[1] 600	23,686.3	69.6	1.1	23,757.0	24,015.3	41.675	−.010
Even-temperature interval 70°–80°. $Z]_{70}^{80} = 8{,}728.8$ Int. joules. Mean value of $\alpha]_{70}^{80} = \alpha_m = 41.6847$ Int. joules per g.													
35-I	June 10, 1927	487.107	80.078	90.269	1,380	600	29,580.7	84.2	3.2	29,668.2	29,111.9	41.673	.007
36-I	June 13, 1927	487.107	80.043	89.743	1,440	600	29,297.4	87.9	4.2	29,389.5	29,110.4	41.670	.004
37-I	June 16, 1927	487.107	80.201	90.333	1,500	600	29,402.7	91.5	2.9	29,497.3	29,111.7	41.673	.007
44-I	July 13, 1927	326.833	80.725	90.341	1,680	600	21,466.1	100.8	1.9	21,568.8	22,420.2	41.635	−.031
50-I	July 23, 1927	493.054	80.363	90.484	1,440	600	29,623.2	87.5	3.1	29,713.8	29,350.0	41,654	−.012
52-I	July 26, 1927	493.054	79.885	89.879	1,500	600	29,247.9	91.2	2.1	29,341.2	29,356.5	41.667	.001
53-I	July 27, 1927	493.054	80.169	90.355	1,320	600	29,825.0	80.3	2.6	29,907.9	29,357.5	41.669	.003
56-I	Aug. 1, 1927	291.001	79.908	89.551	1,440	600	20,098.1	86.6	2.3	20,187.0	20,936.7	41.671	.005
57-I	Aug. 2, 1927	291.001	79.981	90.006	1,380	600	20,910.8	83.1	1.3	20,995.2	20,941.0	41.678	.012
58-I	Aug. 3, 1927	291.001	80.016	89.981	1,140	600	20,793.9	68.6	1.1	20,863.6	20,934.6	41.656	−.010
59-I	Aug. 4, 1927	291.001	80.218	90.242	1,140	600	20,931.7	68.6	2.0	21,002.3	20,948.7	41.705	.039
62-I	Aug. 9, 1927	366.801	80.268	89.928	1,140	[1] 600	23,206.5	68.6	1.2	23,276.3	24,093.9	41.661	−.005
63-I	Aug. 10, 1927	366.801	80.086	89.938	1,080	[1] 600	23,665.6	64.9	1.4	23,731.9	24,088.1	41.645	−.021
Even-temperature interval 80°–90°. $Z]_{80}^{90} = 8{,}812.6$ Int. joules. Mean value of $\alpha]_{80}^{90} = \alpha_m = 41.6656$ Int. joules per g.													

35-J	June 10, 1927	487.107	90.269	100.480	1,560	600	29,722.6	93.0	4.2	29,819.9	29,198.6	41.689	−.001
36-J	June 13, 1927	487.107	90.139	100.239	1,800	600	29,388.1	107.4	4.1	29,499.6	29,205.7	41.704	.014
37-J	June 16, 1927	487.107	90.333	100.495	1,440	600	29,582.9	85.4	3.1	29,671.4	29,195.1	41.682	−.068
44-J	July 13, 1927	326.833	90.341	100.073	1,440	600	21,814.7	85.2	2.1	21,901.9	22,500.2	41.638	−.052
50-J	July 23, 1927	493.054	90.484	100.361	1,500	600	28,999.0	89.0	3.5	29,091.5	29,450.9	41.698	.008
52-J	July 26, 1927	493.054	89.879	100.022	1,440	600	29,781.8	85.7	2.0	29,869.5	29,447.4	41.691	.001
53-J	July 27, 1927	493.054	90.355	100.212	1,380	600	28,943.5	82.1	2.2	29,027.8	29,444.5	41.685	−.005
56-J	Aug. 1, 1927	291.001	89.551	100.097	1,440	660	22,090.6	85.4	3.4	22,179.4	21,030.2	41.714	.024
57-J	Aug. 2, 1927	291.001	90.007	100.164	1,320	600	21,279.8	78.1	1.8	21,359.7	21,029.1	41.710	.020
58-J	Aug. 3, 1927	291.001	89.981	100.065	1,340	600	21,118.0	79.2	.8	21,198.0	21,023.0	41.689	−.001
59-J	Aug. 4, 1927	291.001	90.242	100.217	1,170	660	20,910.2	69.3	1.0	20,980.5	21,028.8	41.709	.019
62-J	Aug. 9, 1927	366.801	89.928	100.894	1,200	[1] 660	26,448.4	71.4	1.4	26,521.2	24,180.6	41.682	−.008
63-J	Aug. 10, 1927	366.801	89.992	99.976	1,140	[1] 600	24,071.3	67.9	1.5	24,140.7	24,178.3	41.676	−.014

Even-temperature interval 90°–100°. $Z]_{90}^{100}=8{,}891.5$ Int. joules. Mean value of $\alpha]_{90}^{100}=\alpha_m=41.6896$ Int. joules per g.

38-K	June 17, 1927	487.107	99.716	109.876	1,920	600	29,644.7	112.2	3.4	29,760.3	29,292.5	41.686	.008
39-K	June 20, 1927	487.107	99.606	109.837	1,380	600	29,878.6	80.7	3.9	29,963.2	29,288.4	41.677	−.001
52-K	July 26, 1927	493.054	100.126	110.223	1,320	600	29,749.8	76.8	3.5	29,830.1	29,536.8	41.678	.000
53-K	July 27, 1927	493.054	100.212	109.985	1,440	600	28,775.3	83.7	2.0	28,861.0	29,534.2	41.673	−.005
56-K	Aug. 1, 1927	291.001	100.097	109.936	1,440	600	20,694.7	84.7	2.2	20,781.6	21,123.2	41.704	.026
60-K	Aug. 5, 1927	291.001	100.049	110.218	1,320	600	21,402.1	77.3	.8	21,480.2	21,119.3	41.691	.013
87-K	Nov. 8, 1927	475.903	100.135	110.796	1,800	1,080	30,626.1	104.5	2.2	30,732.8	28,823.8	41.682	.004
89-K	Nov. 10, 1927	475.903	100.104	110.293	1,800	1,200	29,267.8	104.4	.0	29,372.2	28,825.7	41.686	.008
90-K	Nov. 11, 1927	475.903	100.066	110.309	1,740	1,200	29,427.5	101.0	.0	29,528.5	28,825.4	41.686	.008
93-K	Nov. 15, 1927	263.730	100.103	110.107	1,740	1,200	19,881.9	100.9	−.5	19,982.2	19,973.2	41.656	−.022
94-K	Nov. 16, 1927	263.730	100.030	110.044	1,740	1,200	19,911.6	100.9	−1.1	20,011.4	19,984.0	41.697	.019
95-K	Nov. 25, 1927	267.764	100.217	110.046	1,740	1,200	19,700.8	101.0	−.4	19,801.4	20,144.5	41.669	−.009
96-K	Nov. 26, 1927	267.764	100.095	110.044	1,800	1,200	19,938.7	104.6	−2.0	20,041.3	20,144.5	41.669	−.009
97-K	Nov. 28, 1927	267.764	100.188	110.051	1,680	1,200	19,780.0	97.6	−2.4	19,875.2	20,150.3	41.690	.012
112-K	Jan. 30, 1928	301.182	100.197	110.164	1,800	1,200	21,366.3	103.5	2.1	21,471.9	21,542.1	41.686	.008
113-K	Jan. 31, 1928	410.025	100.032	110.331	1,800	1,260	26,747.7	109.8	.4	26,857.9	26,077.0	41.680	.002
114-K	Feb. 1, 1928	410.025	99.974	110.452	1,860	1,260	27,208.5	103.5	1.3	27,313.3	26,066.3	41.654	−.024
115-K	Feb. 6, 1928	419.333	100.049	110.178	2,100	1,260	26,669.4	128.3	1.4	26,799.1	26,457.4	41.662	−.016

Even-temperature interval 100°–110°. $Z]_{100}^{110}=8{,}987.2$ Int. joules. Mean value of $\alpha]_{100}^{110}=\alpha_m=41.6782$ Int. joules per g.

[1] See footnote 1, p. 445.

TABLE 3.—*Principal data from α experiments* $Q]_1^2 = M\alpha]_1^2 + Z]_1^2$. $\alpha]_1^2 = \left[H - L\frac{u}{u'-u}\right]_1^2$—Continued

Experiment No.	Date	Mass of water M	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Time of electric heating	Total electric energy	Pump energy	Heat leak	Entire energy added Q	Energy for even temperature intervals $Q]_1^2$	$\alpha]_1^2$	Residual $\alpha]_1^2 - \alpha_m$
		g	°*C.*	°*C.*	*Seconds*	*Seconds*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Iut. joules*	*Int. joules/g*	*Int. joules/g*
38-L	June 17, 1927	487.107	109.876	120.052	1,500	600	29,817.4	85.9	3.6	29,906.9	29,389.0	41.676	−0.008
39-L	June 20, 1927	487.107	109.837	120.106	1,380	600	30,097.7	79.1	3.8	30,180.6	29,390.4	41.678	−.006
52-L	July 26, 1927	493.054	110.223	120.277	1,320	600	29,725.2	75.5	3.6	29,804.3	29,640.4	41.683	−.001
56-L	Aug. 1, 1927	291.001	109.936	119.903	1,380	600	21,073.2	80.5	2.8	21,156.5	21,226.5	41.711	.027
60-L	Aug. 5, 1927	291.001	110.218	120.156	1,380	600	21,013.1	80.4	2.1	21,095.6	21,224.1	41.703	.019
87-L	Nov. 8, 1927	475.903	110.796	120.192	1,800	1,080	27,081.0	102.8	2.1	27,185.9	28,927.0	41.686	.002
89-L	Nov. 10, 1927	475.903	110.293	120.441	1,980	1,200	29,247.3	113.1	.5	29,360.9	28,929.7	41.691	.007
90-L	Nov. 11, 1927	475.903	110.309	120.338	1,800	1,200	28,912.4	102.7	.5	29,015.6	28,928.8	41.690	.006
93-L	Nov. 15, 1927	263.730	110.107	120.073	2,300	1,200	19,867.5	131.3	−.4	19,998.4	20,065.5	41.622	−.062
95-L	Nov. 25, 1927	267.764	110.046	119.826	1,980	1,200	19,692.9	113.6	−.5	19,806.0	20,251.9	41.691	.007
96-L	Nov. 26, 1927	267.764	110.044	119.937	1,740	1,200	19,938.1	99.8	−2.5	20,035.4	20,249.9	41.684	.000
97-L	Nov. 28, 1927	267.764	110.051	119.867	1,800	1,200	19,775.7	103.2	−3.6	19,875.3	20,247.5	41.675	−.009
112-L	Jan. 30, 1928	301.182	110.164	119.951	1,920	1,200	21,073.4	114.7	1.8	21,189.9	21,650.2	41.708	.024
113-L	Jan. 31, 1928	410.025	110.331	119.623	1,620	1,140	24,232.0	96.8	1.4	24,330.2	26,183.7	41.691	.007
114-L	Feb. 1, 1928	410.025	110.452	120.030	1,740	1,140	24,967.8	103.9	.8	25,072.5	26,173.2	41.667	−.017
115-L	Feb. 6, 1928	419.333	110.178	120.033	1,740	1,200	26,077.4	103.9	1.8	26,183.1	26,565.8	41.679	−.005
Even-temperature interval 110°–120°				$Z]_{110}^{120} = 9{,}088.6$ Int. joules.			Mean value of $\alpha]_{110}^{120} = \alpha_m = 41.6836$ Int. joules per g						
38-M	June 17, 1927	487.107	120.053	130.284	2,760	600	30,029.9	155.3	5.1	30,190.4	29,507.1	41.672	−.005
39-M	June 20, 1927	487.107	120.106	130,389	1,320	600	30,269.9	74.3	3.8	30,347.0	29,508.4	41.674	−.003
52-M	July 26, 1927	493.054	120.277	130.077	1,320	600	29,089.1	74.1	3.6	29,166.8	29,754.5	41.671	−.006
56-M	Aug. 1, 1927	291.001	119.903	130.342	1,380	600	22,195.4	79.7	4.5	22,279.6	21,340.9	41.692	.015
60-M	Aug. 5, 1927	291.001	120.156	130.027	1,380	600	20,985.4	79.8	2.7	21,067.9	21,340.1	41.689	.012
87-M	Nov. 8, 1927	475.903	120.192	130.062	1,740	1,140	28,571.1	98.2	1.9	28,671.2	29,046.4	41.685	.008
89-M	Nov. 10, 1927	475.903	120.440	130.388	1,920	1,200	28,792.1	108.2	−.1	28,900.2	29,046.2	41.684	.007
90-M	Nov. 11, 1927	475.903	120.338	130.138	1,740	1,200	28,370.4	98.1	.2	28,468.7	29,047.9	41.688	.011
95-M	Nov. 25, 1927	267.764	119.826	129.792	1,800	1,200	20,194.2	101.7	−1.2	20,294.7	20,365.8	41.668	−.009
96-M	Nov. 26, 1927	267.764	119.937	129.894	1,680	1,200	20,185.0	94.8	−2.9	20,276.9	20,364.9	41.665	−.012
97-M	Nov. 28, 1927	267.764	119.867	129.957	1,620	1,200	20,462.4	91.4	−3.0	20,550.8	20,369.0	41.680	.003
112-M	Jan. 30, 1928	301.182	119.951	129.945	1,920	1,200	21,634.5	112.0	1.0	21,747.5	21,760.8	41,676	−.001
113-M	Jan. 31, 1928	410.025	119.623	129.890	1,800	1,200	26,889.1	105.0	1.2	26,995.3	26,297.6	41,678	.001
114-M	Feb. 1, 1928	410.025	120.029	130.054	1,680	1,200	26,239.7	96.0	.2	26,357.9	26,291.8	41.664	−.013
115-M	Feb. 6, 1928	419.333	120.033	130.053	1,740	1,200	26,633.2	101.5	1.3	26,736.0	26,681.6	41.669	−.008
Even-temperature interval 120°–130°.				$Z]_{120}^{130} = 9{,}208.6$ Int. joules.			Mean value of $\alpha]_{120}^{130} = \alpha_m = 41.6767$ Int. joules per g.						

87-N	Nov. 8, 1927	475.903	130.062	140.403	1,920	1,200	30,060.6	106.8	1.5	30,168.9	29,177.4	41.712	.011
89-N	Nov. 10, 1927	475.903	130.388	139.984	1,860	1,200	27,895.6	104.2	−.9	27,998.9	29,175.5	41.708	.007
90-N	Nov. 11, 1927	475.903	130.137	139.936	2,700	1,200	28,433.5	150.4	1.7	28,585.6	29,170.2	41.697	−.004
93-N	Nov. 15, 1927	263.730	129.997	139.964	1,860	1,200	20,153.8	103.7	−1.3	20,256.2	20,324.3	41.700	−.001
95-N	Nov. 25, 1927	267.764	129.793	139.792	1,740	1,200	20,392.7	97.0	−1.3	20,488.4	20,493.7	41.704	.003
96-N	Nov. 26, 1927	267.764	129.895	140.089	1,740	1,200	20,796.7	97.0	−3.6	20,890.1	20,492.7	41.701	.000
97-N	Nov. 28, 1927	267.764	129.957	139.988	1,740	1,200	20,461.7	97.0	−1.6	20,557.1	20,493.8	41.705	.004
112-N	Jan. 30, 1928	301.182	129.945	140.009	1,860	1,200	21,921.4	106.3	2.3	22,030.0	21,887.6	41.705	.004
113-N	Jan. 31, 1928	410.025	129.890	140.017	2,100	1,200	26,635.6	120.0	1.6	26,757.2	26,423.3	41.696	−.005
114-N	Feb. 1, 1928	410.025	130.054	140.019	1,680	1,200	26,228.0	96.0	.8	26,324.8	26,417.9	41.683	−.018
115-N	Feb. 6, 1928	419.333	130.053	140.017	1,740	1,200	26,616.5	99.4	1.3	26,717.2	26,812.7	41.700	−.001

Even-temperature interval 130°–140°. $Z]_{130}^{140}$=9,326.7 Int. joules. Mean value of $\alpha]_{130}^{140}=\alpha_m$=41.7008 Int. joules per g.

87-O	Nov. 8, 1927	475.903	140.403	150.687	1,920	1,200	30,043.7	105.7	2.0	20,151.4	29,305.7	41.701	−.012
89-O	Nov. 10, 1927	475.903	139.984	149.949	1,980	1,200	29,103.2	109.0	−2.1	29,210.1	29,312.8	41.716	.003
90-O	Nov. 11, 1927	475.903	139.937	149.957	1,860	1,200	29,274.1	99.2	−.6	29,372.7	29,314.5	41.719	.006
93-O	Nov. 15, 1927	263.730	139.964	150.226	1,800	1,200	20,893.6	99.2	−2.2	20,990.6	20,452.5	41.680	−.033
95-O	Nov. 25, 1927	267.764	139.792	149.969	1,740	1,200	20,906.2	95.9	−2.6	20,999.5	20,633.6	41.728	.015
96-O	Nov. 26, 1927	267.764	140.089	150.219	1,980	1,200	20,789.2	109.2	−3.4	20,895.0	20,625.5	41.698	−.015
97-O	Nov. 28, 1927	267.764	139.988	150.068	1,800	1,200	20,698.9	99.2	−1.8	20,796.3	20,631.5	41.721	.008
112-O	Jan. 30, 1928	301.182	140.010	150.173	1,980	1,200	22,275.7	111.0	2.7	22,389.4	22,031.1	41.738	.025
113-O	Jan. 31, 1928	410.025	140.017	150.213	1,860	1,200	26,983.7	104.3	1.7	27,089.7	26,567.4	41.722	.009
114-O	Feb. 1, 1928	410.025	140.019	149.930	2,100	1,200	26,204.1	117.8	.9	26,322.8	26,559.3	41.703	−.010
115-O	Feb. 6, 1928	419.333	140.017	149.990	2,100	1,200	26,759.6	117.8	2.1	26,879.8	26,951.9	41.713	.000

Even-temperature interval 140°–150°. $Z]_{140}^{150}$=9,460.3 Int. joules. Mean value of $\alpha]_{140}^{150}=\alpha_m$=41.7127 Int. joules per g.

88-P	Nov. 9, 1927	475.903	150.712	160.406	1,920	1,140	28,458.7	104.5	2.3	28,565.5	29,459.1	41.699	−.004
89-P	Nov. 10, 1927	475.903	149.949	160.148	1,740	1,200	29,960.7	94.8	−1.6	30,053.9	29,466.3	41.714	.011
90-P	Nov. 11, 1927	475.903	149.957	160.362	1,860	1,200	30,556.0	101.4	−.4	30,657.0	29,461.4	41.704	.001
93-P	Nov. 15, 1927	263.730	150.226	159.779	1,740	1,140	19,595.1	94.8	−1.7	19,688.2	20,609.4	41.690	−.013
95-P	Nov. 25, 1927	267.764	149.970	160.073	1,740	1,200	20,893.5	94.8	−2.8	20,985.5	20,763.0	41.636	−.067
96-P	Nov. 26, 1927	267.764	150.219	159.963	1,800	1,200	20,159.8	98.0	−3.8	20,254.0	20,785.8	41.721	.018
97-P	Nov. 28, 1927	267.764	150.068	160.066	1,920	1,200	20,696.3	104.6	−2.8	20,798.1	20,795.4	41.757	.053
112-P	Jan. 30, 1928	301.182	150.173	160.256	1,860	1,200	22,263.3	102.0	2.7	22,368.0	22,180.1	41.721	.018
113-P	Jan. 31, 1928	410.025	150.212	160.292	1,920	1,200	26,824.0	105.2	3.3	26,932.5	26,714.0	41.704	.001
114-P	Feb. 1, 1928	410.025	149.930	159.959	1,920	1,200	26,679.6	105.2	−.7	26,784.1	26,706.4	41.685	−.018

Even-temperature interval 150°–160°. $Z]_{150}^{160}$=9,614.5 Int. joules. Mean value of $\alpha]_{150}^{160}=\alpha_m$=41.7027 Int. joules per g.

TABLE 3.—*Principal data from α experiments* $Q]_1^2 = M\alpha]_1^2 + Z]_1^2$. $\alpha]_1^2 = \left[H - L\frac{u}{u'-u}\right]_1^2$—Continued

Experiment No.	Date	Mass of water M	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Time of electric heating	Total electric energy	Pump energy	Heat leak	Entire energy added Q	Energy for even temperature intervals $Q]_1^2$	$\alpha]_1^2$	Residual $\alpha]_1^2 - \alpha_m$
		g	°*C.*	°*C.*	*Seconds*	*Seconds*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules/g*	*Int. joules/g*
88-Q	Nov. 9, 1927	475.903	160.406	170.543	1,860	1,200	29,934.6	100.5	2.1	30,037.2	29,624.3	41.712	0.000
89-Q	Nov. 10, 1927	475.903	160.148	170.158	1,860	1,200	29,539.6	100.5	−2.0	29,638.1	29,623.7	41.711	−.001
90-Q	Nov. 11, 1927	475.903	160.362	170.390	1,740	1,200	29,622.0	94.0	−.3	29,715.7	29,627.2	41.719	.007
93-Q	Nov. 15, 1927	263.730	159.779	170.247	1,860	1,260	21,643.2	100.5	−.8	21,742.9	20,769.1	41.694	−.018
95-Q	Nov. 25, 1927	267.764	160.073	170.086	1,680	1,200	20,882.1	90.7	−1.5	20,971.3	20,950.2	41.742	.030
96-Q	Nov. 26, 1927	267.764	159.963	169.858	1,680	1,200	20,641.3	90.7	−4.0	20,728.0	20,945.6	41.725	.013
97-Q	Nov. 28, 1927	267.764	160.066	169.993	1,740	1,200	20,686.6	94.0	−4.1	20,776.5	20,933.6	41.680	−.032
112-Q	Jan. 30, 1928	301.182	160.256	170.258	1,920	1,200	22,247.7	103.2	2.1	22,353.0	22,341.1	41.728	.016
113-Q	Jan. 31, 1928	410.025	160.292	170.027	1,860	1,200	26,062.1	100.0	1.8	26,163.9	26,874.1	41.707	−.005
114-Q	Feb. 1, 1928	410.025	159.960	170.161	1,920	1,200	27,310.3	103.2	2.2	27,415.7	26,873.3	41.705	−.007
Even-temperature interval 160°–170°. $Z]_{160}^{170} = 9{,}773.3$ Int. joules. Mean value of $\alpha]_{160}^{170} = \alpha_m = 41.7120$ Int. joules per g.													
88-R	Nov. 9, 1927	475.903	170.543	180.113	1,980	1,140	28,412.7	106.0	2.4	28,521.1	29,798.0	41.691	−.010
89-R	Nov. 10, 1927	475.903	170.152	180.220	1,800	1,200	29,937.3	100.9	−4.0	30,034.2	29,813.2	41.723	.022
90-R	Nov. 11, 1927	475.903	170.389	180.213	1,800	1,200	29,189.0	96.3	.1	29,285.4	29,805.0	41.706	.005
93-R	Nov. 15, 1927	263.730	170.248	180.126	1,800	1,200	20,599.2	96.3	−.1	20,695.4	20,945.9	41.667	−.034
95-R	Nov. 25, 1927	267.764	170.086	180.007	1,740	1,200	20,872.7	93.2	−2.1	20,963.8	21,129.4	41.725	.024
96-R	Nov. 26, 1927	267.764	169.859	179.789	1,980	1,200	20,919.0	106.0	−4.1	21,020.9	21,128.8	41.722	.021
97-R	Nov. 28, 1927	267.764	169.993	180.424	1,800	1,260	21,944.9	96.3	−5.0	22,036.2	21,122.2	41.698	−.003
112-R	Jan. 30, 1928	301.182	170.259	180.053	1,800	1,200	21,961.0	95.0	2.4	22,058.4	22,519.1	41.709	.008
113-R	Jan. 31, 1928	410.025	170.027	179.951	1,980	1,200	26,742.4	104.9	.5	26,847.8	27,052.5	41.694	−.007
114-R	Feb. 1, 1928	410.025	170.161	180.245	1,800	1,200	27,179.8	95.3	1.8	27,276.9	27,045.7	41.677	−.024
Even-temperature interval 170°–180°. $Z]_{170}^{180} = 9{,}957.1$ Int. joules. Mean value of $\alpha]_{170}^{180} = \alpha_m = 41.7009$ Int. joules per g.													
88-S	Nov. 9, 1927	475.903	180.113	190.113	1,980	1,200	29,884.1	105.2	.7	29,990.0	29,988.4	41.660	.002
89-S	Nov. 10, 1927	475.903	180.225	190.223	1,680	1,200	29,912.0	89.2	−4.5	29,996.7	29,997.7	41.680	.022
90-S	Nov. 11, 1927	475.903	180.213	190.040	1,680	1,200	29,377.6	89.3	−.6	29,466.3	29,983.1	41.649	−.009
93-S	Nov. 15, 1927	263.730	180.126	189.651	1,800	1,140	20,040.2	95.7	−2.4	20,133.5	21,142.4	41.634	−.024
95-S	Nov. 25, 1927	267.764	180.007	189.949	1,800	1,200	21,109.9	95.6	−3.1	21,202.4	21,326.3	41.693	.035
96-S	Nov. 26, 1927	267.764	179.789	189.870	1,800	1,200	21,352.7	95.6	−3.9	21,444.4	21,319.6	41.668	.010
97-S	Nov. 28, 1927	267.764	180.424	189.889	1,680	1,140	20,095.1	89.2	−5.5	20,178.8	21,315.9	41.654	−.004
112-S	Jan. 30, 1928	301.182	180.053	189.885	1,860	1,200	22,228.2	96.5	.3	22,325.0	22,706.9	41.651	−.007
113-S	Jan. 31, 1928	410.025	179.952	189.804	1,860	1,200	26,734.6	96.5	.7	26,831.8	27,238.4	41.646	−.012
114-S	Feb. 1, 1928	410.025	180.245	189.753	1,860	1,140	25,798.9	96.5	1.6	25,897.0	27,238.1	41.646	−.012
Even-temperature interval 180°–190°. $Z]_{180}^{190} = 10{,}162.4$ Int. joules. Mean value of $\alpha]_{180}^{190} = \alpha_m = 41.6578$ Int. joules per g.													

88-T	Nov. 9, 1927	475.903	190.112	200.327	2,040	1,200	30,744.5	107.5	−1.1	30,850.9	30,197.2	41.657	.005
89-T	Nov. 10, 1927	475.903	190.223	200.149	1,740	1,200	29,887.9	91.7	−2.5	29,977.1	30,196.1	41.655	.003
90-T	Nov. 11, 1927	475.903	190.040	200.129	1,740	1,200	30,388.6	91.7	−1.9	30,478.4	30,208.7	41.681	.029
93-T	Nov. 15, 1927	263.730	189.651	200.059	1,860	1,260	22,132.1	98.0	−2.7	22,227.4	21,357.3	41.651	−.001
95-T	Nov. 25, 1927	267.764	189.949	199.910	1,860	1,200	21,354.3	98.0	−3.1	21,449.2	21,535.9	41.691	.039
96-T	Nov. 26, 1927	267.764	189.870	200.046	1,800	1,200	21,814.9	94.8	−5.9	21,903.8	21,523.3	41.644	−.008
97-T	Nov. 28, 1927	267.764	189.889	200.144	1,680	1,200	21,987.7	88.5	−4.7	22,071.5	21,531.3	41.674	.022
112-T	Jan. 30, 1928	301.182	189.885	199.763	1,860	1,200	22,529.8	94.8	3.2	22,627.8	22,909.8	41.627	−.025
113-T	Jan. 31, 1928	410.025	189.804	199.744	1,980	1,200	27,167.3	101.1	2.1	27,270.5	27,436.9	41.618	−.034
114-T	Feb. 1, 1928	410.025	189.755	199.677	1,860	1,200	27,126.8	94.8	1.7	27,223.3	27,440.4	41.626	−.026

Even-temperature interval 190°–200°. $Z]_{190}^{200}$=10,372.7 Int. joules. Mean value of $\alpha]_{190}^{200}=\alpha_m$=41.6514 Int. joules per g.

88-U	Nov. 9, 1927	475.903	200.327	210.173	1,860	1,200	29,858.4	97.3	−3.3	29,952.4	30,414.3	41.576	0.011
89-U	Nov. 10, 1927	475.903	200.150	210.146	1,740	1,200	30,312.9	91.0	−5.1	30,398.8	30,406.1	41.558	−.007
90-U	Nov. 11, 1927	475.903	200.129	210.145	1,800	1,200	30,367.6	94.1	−2.1	30,459.6	30,408.1	41.563	−.002
92-U	Nov. 14, 1927	263.730	200.530	210.347	1,800	1,200	21,122.8	94.1	−2.9	21,214.0	21,599.4	41.600	.035
93-U	Nov. 15, 1927	263.730	200.060	210.002	1,800	1,200	21,380.0	94.1	−3.0	21,471.1	21,595.4	41.585	.020
95-U	Nov. 25, 1927	267.764	199.910	209.991	1,680	1,200	21,851.6	87.8	−5.4	21,934.0	21,757.7	41.564	−.001
96-U	Nov. 26, 1927	267.764	200.046	209.954	1,740	1,200	21,467.8	90.9	−4.9	21,553.8	21,755.5	41.556	−.009
97-U	Nov. 28, 1927	267.764	200.145	210.019	1,680	1,200	21,403.3	87.8	−5.7	21,485.4	21,746.4	41.522	−.043

Group I, interval 200°–210°. $Z]_{200}^{210}$=10,628.3 Int. joules. Weight 1 to 5

173-U	Dec. 17, 1928	292.871	200.641	210.265	1,440	720	22,483.2	109.2	.0	22,592.4	23,464	41.490	−.013
174-U	Dec. 18, 1928	408.332	200.143	209.898	1,260	720	27,453.0	95.5	3.1	27,551.6	28,243	41.462	−.041
175-U	Dec. 19, 1928	414.265	200.153	210.104	1,320	720	28,250.3	100.1	−.9	28,349.5	28,486	41.455	−.048
176-U	Dec. 20, 1928	279.315	200.076	212.371	1,200	720	28,100.7	91.0	2.3	28,194.0	22,900	41.484	−.019
177-U	Dec. 21, 1928	413.267	200.147	210.167	1,320	720	28,430.4	100.1	1.5	28,532.0	28,472	41.521	.018
178-U	Dec. 26, 1928	288.124	200.157	209.947	1,140	720	22,690.9	86.4	−1.0	22,776.3	23,264	41.479	−.024
179-U	Dec. 27, 1928	415.134	200.092	210.123	1,500	720	28,512.2	113.7	1.0	28,626.9	28,537	41.491	−.012
181-U	Dec. 29, 1928	419.612	200.173	209.923	1,140	720	27,922.1	86.4	−.4	28,008.1	28,725	41.496	−.007
183-U	Jan. 2, 1929	285.531	200.187	209.956	1,240	720	22,513.7	94.0	3.0	22,610.7	23,144	41.436	−.067
184-U	Jan. 3, 1929	286.319	200.150	210.187	1,080	720	23,200.7	81.9	−.3	23,282.3	23,192	41.489	−.014
189-U	Jan. 22, 1929	420.292	200.137	210.344	1,140	720	29,293.2	63.0	1.7	29,357.9	28,757	41.505	.002
190-U	Jan. 23, 1929	277.212	200.207	210.231	1,260	720	22,819.9	69.7	1.8	22,891.4	22,832	41.554	.051
191-U	Jan. 24, 1929	278.960	200.317	210.323	1,080	720	22,826.4	82.0	.1	22,908.5	22,888	41.494	−.009
193-U	Jan. 26, 1929	419.184	200.027	210.144	1,080	720	28,964.8	82.0	.8	29,047.6	28,716	41.517	.014
195-U	Jan. 31, 1929	421.532	199.989	210.035	1,080	720	28,844.0	82.8	1.9	28,928.7	28,796	41.475	−.028

Group II, interval 200°–210°. $Z]_{200}^{210}$=11,312.8 Int. joules. Weight 5 to 1

Even-temperature interval 200°–210°. Mean value of $\alpha]_{200}^{210}=\alpha_m$=41.5026 Int. joules per g.

TABLE 3.—*Principal data from α experiments* $Q]_1^2 = M\alpha]_1^2 + Z]_1^2$. $\alpha]_1^2 = \left[H - L\frac{u}{u'-u}\right]_1^2$—Continued

Experiment No.	Date	Mass of water M	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Time of electric heating	Total electric energy	Pump energy	Heat leak	Entire energy added Q	Energy for even temperature intervals $]Q]_1^2$	$\alpha]_1^2$	Residual $\alpha]_1^2 - \alpha_m$
		g	°*C.*	°*C.*	*Seconds*	*Seconds*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules/g*	*Int. joules/g*
173-V	Dec. 17, 1928	292.871	210.265	220.213	1,200	720	23,493.2	89.6	0.7	23,585.5	23,701	41.406	0.014
174-V	Dec. 18, 1928	408.332	209.898	219.874	1,200	720	28,312.3	89.6	.1	28,402.0	28,473	41.383	−.008
175-V	Dec. 19, 1928	414.265	210.104	220.110	1,140	720	28,655.4	85.1	−2.5	28,738.0	28,718	41.382	−.009
177-V	Dec. 21, 1928	413.267	210.167	220.239	1,200	720	28,795.3	89.6	2.0	28,886.9	28,675	41.378	−.013
178-V	Dec. 26, 1928	288.124	209.947	219.928	1,200	720	23,369.9	89.6	−1.2	23,458.3	23,504	41.403	.012
179-V	Dec. 27, 1928	415.134	210.123	220.153	1,140	720	28,763.9	85.1	−3.5	28,845.5	28,755	41.385	−.006
181-V	Dec. 29, 1928	419.612	209.923	220.051	1,200	720	29,235.1	89.6	−2.0	29,322.7	28,953	41.415	.024
183-V	Jan. 2 1929	285.531	209.956	219.918	1,200	720	23,202.1	89.6	1.2	23,292.9	23,384	41.359	−.032
184-V	Jan. 3, 1929	286.319	210.187	220.189	1,080	720	23,356.7	80.6	−.7	23,436.6	23,428	41.399	.008
189-V	Jan. 22, 1929	420.292	210.344	220.417	1,200	720	29,141.5	65.4	2.7	29,209.6	28,989	41.434	.043
190-V	Jan. 23, 1929	277.212	210.231	220.137	1,140	720	22,778.1	62.2	1.5	22,841.8	23,054	41.409	.018
191-V	Jan. 24, 1929	278.960	210.323	220.222	1,200	720	22,798.2	89.7	.5	22,888.4	23,115	41.369	−.022
192-V	Jan. 25, 1929	419.602	210.339	220.278	1,260	720	28,670.7	94.2	1.2	28,766.1	28,935	41.373	−.018
193-V	Jan. 26, 1929	419.181	210.144	219.963	1,080	720	28,318.4	80.7	.5	28,399.6	28,916	41.369	−.022
195-V	Jan. 31, 1929	421.532	210.035	220.048	1,140	720	28,973.2	86.5	3.3	29,063.0	29,024	41.395	.004
Even-temperature interval 210°–220°. $Z]_{210}^{220} = 11{,}574.8$ Int. joules. Mean value of $\alpha]_{210}^{220} = \alpha_m = 41.3908$ Int. joules per g.													
173-W	Dec. 17, 1928	292.871	220.213	230.171	1,200	720	23,775.0	88.0	−.8	23,862.2	23,957	41.355	.017
174-W	Dec. 18, 1928	408.332	219.874	230.201	1,260	720	29,562.2	92.4	.3	29,654.9	28,715	41.313	−.025
175-W	Dec. 19, 1928	414.265	222.371	230.407	1,020	600	23,221.6	74.8	−2.4	23,294.0	28,954	41.299	−.039
176-W	Dec. 20, 1928	279.315	220.264	229.968	1,140	720	22,623.9	83.6	−6.5	22,701.0	23,390	41.332	−.006
177-W	Dec. 21, 1928	413.267	220.239	230.305	1,140	720	29,054.7	83.6	−.5	29,137.8	28,941	41.367	.029
178-W	Dec. 26, 1928	288.124	219.928	230.140	1,200	720	24,176.4	88.0	−1.0	24,263.4	23,759	41.349	.011
179-W	Dec. 27, 1928	415.134	220.153	230.264	1,140	720	29,249.2	83.6	−2.2	29,330.6	29,004	41.333	−.005
181-W	Dec. 29, 1928	419.612	220.051	230.114	1,140	720	29,307.0	83.6	1.6	29,392.2	29,200	41.359	.021
183-W	Jan. 2, 1929	285.531	219.918	230.993	1,320	780	26,093.7	96.8	−3.8	26,186.7	23,632	41.280	−.058
184-W	Jan. 3, 1929	286.319	220.189	230.244	1,260	720	23,730.0	92.4	−.1	23,822.3	23,686	41.355	.017
189-W	Jan. 22, 1929	420.292	220.417	230.316	1,080	720	28,885.6	57.7	1.2	28,944.5	29,230	41.363	.025
190-W	Jan. 23, 1929	277.212	220.137	230.131	1,140	720	23,238.9	60.9	.8	23,300.6	23,312	41.364	.026
191-W	Jan. 24, 1929	278.960	220.222	230.182	1,140	720	23,205.3	83.6	−.5	23,288.4	23,376	41.334	−.004
193-W	Jan. 26, 1929	419.181	219.963	229.940	1,140	720	29,015.5	83.6	1.4	29,100.5	29,170	41.330	−.008
195-W	Jan. 31, 1929	421.532	220.048	229.960	1,080	720	28,934.3	79.2	.5	29,014.0	29,272	41.341	.003
Even-temperature interval 220°–230°. $Z]_{220}^{230} = 11{,}845.4$ Int. joules. Mean value of $\alpha]_{220}^{230} = \alpha_m = 41.3384$ Int. joules per g.													

173—X	Dec. 17, 1928	292.871	230.171	240.112	1,320	720	23,998.6	95.0	.6	24,094.2	24,233	41.345	.043
174—X	Dec. 18, 1928	408.332	230.201	240.262	1,140	720	29,087.1	82.1	.0	29,169.2	28,986	41.294	−.008
175—X	Dec. 19, 1928	414.265	230.407	240.242	1,260	720	28,663.1	90.7	−1.5	28,752.3	29,226	41.282	−.020
176—X	Dec. 20, 1928	279.315	229.968	239.850	1,080	720	23,304.6	77.8	.6	23,383.0	23,665	41.318	.016
177—X	Dec. 21, 1928	413.267	230.305	240.364	1,140	720	29,294.1	82.1	−1.5	29,374.7	29,193	41.302	.000
178—X	Dec. 26, 1928	288.124	230.140	240.229	1,260	720	24,147.0	90.7	.3	24,238.0	24,019	41.284	−.018
179—X	Dec. 27, 1928	415.134	230.264	240.361	1,080	720	29,481.5	77.8	−2.9	29,556.4	29,264	41.287	−.015
181—X	Dec. 29, 1928	419.612	230.116	240.268	1,200	720	29,830.1	86.4	−1.1	29,915.4	29,461	41.316	.014
183—X	Jan. 2, 1929	285.531	230.993	240.422	1,320	660	22,460.2	95.0	−2.0	22,553.2	23,900	41.241	−.061
184—X	Jan. 3, 1929	286.319	230.244	240.245	1,080	720	23,890.6	77.7	−1.4	23,966.9	23,958	41.331	.029
189—X	Jan. 22, 1929	420.292	230.316	240.120	1,080	720	28,865.7	56.6	−.9	28,921.4	29,494	41.328	.026
190—X	Jan. 23, 1929	277.212	230.131	240.215	1,200	720	23,716.6	62.9	.7	23,780.2	23,577	41.314	.012
191—X	Jan. 24, 1929	278.960	230.182	240.213	1,080	720	23,640.8	77.7	.8	23,719.3	23,640	41.281	−.021
193—X	Jan. 26, 1929	419.181	229.940	239.904	1,140	720	29,251.3	82.1	−2.9	29,330.5	29,438	41.304	.002
195—X	Jan. 31, 1929	421.532	229.960	239.937	1,080	720	29,386.8	77.7	1.0	29,465.5	29,534	41.301	−.001

Even-temperature interval 230°–240°. $Z]_{230}^{240}$=12,124.2 Int. joules. Mean value of $\alpha]_{230}^{240}=\alpha_m$=41.3025 Int. joules per g.

173—Y	Dec. 17, 1928	292.871	240.112	250.217	1,200	720	24,688.6	85.0	−.7	24,772.9	24,511	41.245	.003
174—Y	Dec. 18, 1928	408.332	240.262	250.209	1,140	720	29,030.4	80.7	−3.3	29,107.8	29,257	41.205	−.037
175—Y	Dec. 19, 1928	414.265	240.242	250.142	1,140	720	29,147.9	80.7	−3.6	29,225.0	29,515	41.238	−.004
176—Y	Dec. 20, 1928	279.315	239.850	249.857	1,140	720	23,886.7	80.8	−.6	23,966.9	23,955	41.256	.014
177—Y	Dec. 21, 1928	413.267	240.364	250.363	1,080	720	29,405.1	76.5	−1.5	29,480.1	29,472	41.234	−.008
178—Y	Dec. 26, 1928	288.124	240.229	250.289	1,200	720	24,379.1	85.0	−1.6	24,462.5	24,308	41.220	−.022
179—Y	Dec. 27, 1928	415.134	240.361	250.359	1,380	720	29,446.7	97.7	−2.2	29,542.2	29,537	41.205	−.037
181—Y	Dec. 29, 1928	419.612	240.268	250.295	1,080	720	29,769.5	76.5	−1.4	29,844.6	29,757	41.289	.047
183—Y	Jan. 2, 1929	285.531	240.422	250.441	1,200	720	24,166.5	85.0	−.1	24,251.4	24,192	41.188	−.054
184—Y	Jan. 3, 1929	286.319	240.245	250.234	1,140	720	24,143.0	80.7	−1.0	24,222.7	24,242	41.249	.007
189—Y	Jan. 22, 1929	420.292	240.120	249.914	1,020	720	29,116.2	52.7	.7	29,169.6	29,783	41.284	.042
190—Y	Jan. 23, 1929	277.212	240.215	250.225	1,140	720	23,852.5	58.9	.4	23,911.8	23,881	41.302	.000
191—Y	Jan. 24, 1929	278.960	240.213	250.331	1,200	720	24,135.6	85.0	3.8	24,224.4	23,934	41.234	−.008
193—Y	Jan. 26, 1929	419.181	239.904	249.947	1,080	720	29,760.1	76.5	−.4	29,836.2	29,711	41.222	−.020
195—Y	Jan. 31, 1929	421.532	239.937	250.017	1,080	720	29,974.3	76.5	1.0	30,051.8	29,814	41.236	−.006

Even-temperature interval 240°–250°. $Z]_{240}^{250}$=12,431.5 Int. joules. Mean value of $\alpha]_{240}^{250}=\alpha_m$=41.2423 Int. joules per g.

TABLE 3.—*Principal data from α experiments* $Q]_1^2 = M\alpha]_1^2 + Z]_1^2$. $\alpha]_1^2 = \left[H - L\frac{u}{u'-u}\right]_1^2$—Continued

Experiment No.	Date	Mass of water M	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Time of electric heating	Total electric energy	Pump energy	Heat leak	Entire energy added Q	Energy for even temperature intervals $Q]_1^2$	$\alpha]_1^2$	Residual $\alpha]_1^2 - \alpha_m$
		g	°*C.*	°*C.*	*Seconds*	*Seconds*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules/g*	*Int. joules/g*
173-Z	Dec. 17, 1928	292.871	250.217	260.287	1,200	720	24,926.0	83.6	−2.7	25,006.9	24,825	41.162	0.035
174-Z	Dec. 18, 1928	408.332	250.209	260.169	1,260	720	29,356.5	87.8	−.9	29,443.4	29,555	41.107	−.020
175-Z	Dec. 19, 1928	414.265	250.142	260.129	1,200	720	29,690.6	83.6	−3.1	29,771.1	29,805	41.122	−.005
176-Z	Dec. 20, 1928	279.315	249.857	260.426	1,140	720	25,563.4	79.4	−1.8	25,641.0	24,255	41.120	−.007
177-Z	Dec. 21, 1928	413.267	250.363	260.285	1,260	720	29,464.0	87.9	−1.6	29,550.2	29,773	41.144	.017
178-Z	Dec. 26, 1928	288.124	250.289	260.266	1,260	720	24,469.0	87.8	−1.6	24,555.2	24,603	41.070	−.057
179-Z	Dec. 27, 1928	415.134	250.359	260.241	1,200	720	29,405.6	83.6	−2.5	29,486.7	29,830	41.096	−.031
181-Z	Dec. 29, 1928	419.612	250.295	260.163	1,260	720	29,555.1	87.8	.0	29,642.9	30,032	41.139	.012
183-Z	Jan. 2, 1929	285.531	250.441	260.077	1,260	720	23,545.0	87.8	.7	23,633.5	24,517	41.142	.015
184-Z	Jan. 3, 1929	286.319	250.234	260.181	1,080	720	24,345.3	75.2	−.3	24,420.2	24,544	41.123	−.004
189-Z	Jan. 22, 1929	420.292	249.914	259.932	1,080	720	30,067.2	54.9	.0	30,122.1	30,071	41.165	.038
190-Z	Jan. 23, 1929	277.212	250.225	260.210	1,320	720	24,094.0	67.2	1.0	24,162.2	24,192	41.204	.077
191-Z	Jan. 24, 1929	278.960	250.331	260.486	1,560	720	24,504.0	108.8	.9	24,613.7	24,226	41.068	−.059
195-Z	Jan. 31, 1929	421.532	250.017	260.048	1,140	720	30,115.8	79.4	.3	30,195.5	30,102	41.117	−.010
Even-temperature interval 250°–260°. $Z]_{250}^{260} = 12{,}769.7$ Int. joules. Mean value of $\alpha]_{250}^{260} = \alpha_m = 41.1273$ Int. joules per g.													
173-&	Dec. 17, 1928	292.871	260.287	270.374	1,460	720	25,288.1	100.0	−5.2	25,382.9	25,152	41.096	.034
174-&	Dec. 18, 1928	408.332	260.169	270.165	1,340	720	29,790.8	91.8	−6.9	29,875.7	29,882	41.059	−.003
175-&	Dec. 19, 1928	414.265	260.129	270.232	1,320	720	30,357.5	90.4	1.1	30,449.0	30,133	41.077	.015
176-&	Dec. 20, 1928	279.315	260.426	270.044	1,560	720	23,552.5	106.9	−1.4	23,658.0	24,590	41.078	.016
177-&	Dec. 21, 1928	413.267	260.285	270.200	1,320	720	29,748.4	90.4	.6	29,839.4	30,087	41.065	.003
178-&	Dec. 26, 1928	288.124	260.266	270.249	1,820	720	24.773.7	124.7	3.9	24,902.3	24,937	41.026	−.036
179-&	Dec. 27, 1928	415.134	260.241	270.114	1,380	720	29,673.9	94.5	−2.3	29,766.1	30,143	41.015	−.047
183-&	Jan. 2, 1929	285.531	260.077	269.831	1,500	720	24,121.0	102.7	2.0	24,225.7	24,839	41.056	−.006
184-&	Jan. 3, 1929	286.319	260.181	270.165	1,140	720	24,770.1	78.1	.8	24,849.0	24,883	41.096	.034
189-&	Jan. 22, 1929	420.292	259.932	270.044	1,440	720	30,650.3	71.8	.1	30,722.2	30,382	41.080	.018
190-&	Jan. 23, 1929	277.212	260.210	270.122	1,380	720	24,217.7	68.8	3.5	24,290.0	24,500	41.065	.003
191-&	Jan. 24, 1929	278.960	260.486	270.255	1,080	720	23,927.6	73.9	.5	24,002.0	24,557	41.012	−.050
195-&	Jan. 31, 1929	421.532	260.048	269.958	1,080	720	30,080.7	74.0	1.4	30,156.1	30,429	41.071	.009
Even-temperature interval 260°–270°. $Z]_{260}^{270} = 13{,}116.3$ Int. joules. Mean value of $\alpha]_{260}^{270} = \alpha_m = 41.0618$ Int. joules per g.													

TABLE 3 (appendix).—*Principal data from α experiments conducted over intervals of more than 10°*

Experiment No.	Date	Mass of water, M	Initial temperature, θ_1	Final temperature, θ_2	Total time of experiment	Time of electric heating	Total electric energy	Pump energy	Heat leak	Entire energy added, Q	Even-temperature interval	Energy for even-temperature interval, $Q]_1^2$
		g	*° C*	*° C*	*Seconds*	*Seconds*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*° C*	*Int. joules*
45	July 14, 1927	326.833	9.209	40.071	2,760	1,860	67,878.1	205.7	2.6	68,086.4	10–40	66,189.6
45	do	326.833	40.071	70.327	2,880	1,800	67,030.5	186.0	6.9	67,223.4	40–70	66,649.2
45	do	326.833	70.327	99.590	2,760	1,740	65,455.7	212.0	5.3	65,673.0	70–100	67,323.7
46	July 16, 1927	326.833	39.576	69.960	3,060	1,740	67,285.2	196.0	6.9	67,488.1	40–70	66,638.6
46	do	326.833	69.960	99.945	2,580	1,740	67,094.2	154.0	5.9	67,254.1	70–100	67,284.3
51	July 25, 1927	493.054	70.093	100.031	2,940	1,800	87,736.7	178.0	4.9	87,919.6	70–100	88,094.9
53	July 27, 1927	493.054	1.628	19.809	3,720	1,080	52,505.8	222.4	3.5	52,731.7	0–20	58,020.6
54	July 28, 1927	493.054	.826	99.790	8,040	6,180	288,001.5	593.6	12.1	288,607.2	0–100	291,612.9
55	July 29, 1927	493.054	.604	99.477	8,160	6,120	287,696.3	595.3	10.8	288,302.4	0–100	291,588.2
56	Aug. 1, 1927	291.001	6.304	58.267	3,120	2,100	106,856.5	222.8	7.3	107,086.6	0–60	123,643.4
56	do	291.001	58.267	79.908	6,120	1,380	44,869.7	190.7	5.9	45,066.3	60–80	41,657.6
60	Aug. 5, 1927	291.001	.566	100.048	6,780	5,940	205,734.5	464.9	4.0	206,203.4	0–100	207,253.0
67	Sept. 26, 1927	495.653	1.041	99.483	7,380	6,300	287,605.5	505.2	9.0	288,119.7	0–100	292,688.8
68	Sept. 29, 1927	507.031	.949	99.607	6,900	5,760	292,942.9	479.5	10.3	293,432.7	0–100	297,430.0
69	Sept. 30, 1927	507.031	.682	99.950	6,960	5,880	294,750.4	474.7	14.2	295,239.3	0–100	297,413.0
70	Oct. 3, 1927	275.167	.560	99.755	7,680	6,420	198,535.0	524.4	15.3	199,074.7	0–100	200,689.6
71	Oct. 4, 1927	275.167	.766	100.153	7,560	5,820	198,896.7	506.2	13.7	199,416.6	0–100	200,629.6
72	Oct. 5, 1927	275.167	.445	99.716	7,560	[1] 5,820	198,594.6	540.8	18.7	199,154.1	0–100	200,620.5
73	Oct. 6, 1927	498.832	.817	99.728	7,800	[1] 6,120	290,209.4	549.2	17.0	290,775.6	0–100	293,974.5
74	Oct. 7, 1927	498.832	.826	100.325	8,460	[1] 6,120	291,980.6	512.6	15.9	292,509.1	0–100	293,965.5
75	Oct. 8, 1927	498.832	.795	100.311	8,700	[1] 6,180	291,935.5	594.0	20.0	292,549.5	0–100	293,958.1
77	Oct. 13, 1927	258.324	.549	100.160	8,700	[1] 5,940	192,202.0	639.8	18.7	192,860.5	0–100	193,595.3
78	Oct. 14, 1927	258.324	.595	100.319	9,480	[1] 6,000	192,542.5	523.2	17.4	193,083.1	0–100	193,594.7
80	Oct. 24, 1927	268.054	.834	99.893	8,040	[1] 6,120	195,210.7	581.5	19.7	195,811.9	0–100	197,658.5
81	Oct. 25, 1927	268.054	.789	99.787	[7] 7,740	[1] 6,000	195,104.4	559.9	15.7	195,680.0	0–100	197,652.1
82	Oct. 26, 1927	268.054	.670	100.042	7,980	[1] 6,060	195,854.1	577.2	15.0	196,446.3	0–100	197,672.1
83	Oct. 27, 1927	268.054	.506	99.943	8,100	[1] 6,000	195,974.6	582.0	13.6	196,570.2	0–100	197,675.6
84	Oct. 28, 1927	475.116	.786	100.353	8,100	6,060	282,255.8	592.8	13.5	282,862.1	0–100	284,074.3
85	Oct. 29, 1927	475.116	.927	100.068	8,220	6,000	281,037.0	593.9	12.4	281,643.3	0–100	284,073.6
86	Nov. 7, 1927	475.903	100.523	198.456	8,340	7,320	287,655.2	457.1	25.9	288,138.2	100–200	294,320.1
91	Nov. 12, 1927	475.903	100.091	200.368	13,140	8,220	294,532.8	533.7	−7.9	295,058.6	100–200	294,403.2
115	Feb. 6, 1928	419.333	149.990	199.855	6,480	5,880	136,532.9	343.0	−0.8	136,875.1	150–200	137,246.6
116	Feb. 11, 1928	388.753	99.958	199.817	1,086	10,200	257,020.1	605.0	2.2	257,627.3	100–200	258,010.8
185	Jan. 4, 1929	418.892	200.124	270.546	5,820	5,100	207,129.6	419.0	−6.4	207,542.2	200–270	206,249.0

See footnote 1, p. 445.

The entire energy added, Q, is the sum of the total electric energy, pump energy, and heat leak. This entire energy actually added is adjusted to the value it would have had for the even-temperature interval, which was approximated, giving the values of $Q]_1^2$. The calculation of α_m, the mean value of α for an entire group of experiments follows next. This is a least-square calculation, using the formula

$$Q]_1^2 = M\alpha]_1^2 + Z]_1^2$$

This reduction, using the entire group of values of M and $Q]_1^2$ for a single temperature interval, yields the mean value α_m and $Z]_1^2$. Using this value of $Z]_1^2$, which is a constant for the calorimeter as used, the individual values of $\alpha]_1^2$ for each experiment are next computed and compared with the mean for the group.

In the last section of Table 3 the principal data are assembled from those α experiments which were carried out in intervals of more than 10° C. A considerable number of these, particularly between 0° and 100° were made in 100° nonstop experiments which serve as control experiments, adding greater certainty to the values at 100° and 200° C. than the experiments in shorter installments alone give.

In order best to utilize the whole aggregate of α experiments, the results are assembled in Table 4 for the purpose of computing the values of the change in α from 0 to 100, from 100 to 200, and from 200 to 270 from the entire series of energy measurements. With very few exceptions the energy account for each of these three large intervals was kept continuously, the stops at the intermediate 10° points for observing temperatures being made for the purpose of independently establishing these intermediate values of α, but without interruption of the heat-leak and pump-energy control.

TABLE 4.—CALCULATION OF MEAN VALUE OF $\left[H-L\frac{u}{u'-u}\right]_0^{100}$

Experiment No.	Mass of water M	Energy added for even-temperature interval, $Q]_1^2$, Int. joules										$\Sigma Q]_1^2 = Q]_0^{100}$	$\alpha]_0^{100}$	Residual $\alpha]_0^{100}-\alpha_m$
		0°–10°	10°–20°	20°–30°	30°–40°	40°–50°	50°–60°	60°–70°	70°–80°	80°–90°	90°–100°			
	g													
42	326.833	22,032.0	22,025.8											
43	326.833			22,061.9	22,100.6	22,153.5								
44	326.833						22,210.1	22,278.1	22,342.4	22,420.2	22,500.2	222,124.8	417.125	−0.232
45	326.833	22,039.0	←	66,189.6	→	←	66,649.2	→	←	67,323.7	→	222,201.5	417.360	.003
46	326.833	22,033.8	22,024.7	22,057.9	22,103.6	←	66,638.6	→	←	67,284.3	→	222,142.9	417.181	−.176
49	493.054	29,033.6	28,979.0	29,005.8	29,047.4	29,084.1	29,158.3	29,214.1	29,285.6					
50	493.054							29,212.5	29,280.5	29,350.0	29,450.9	291,603.7	417.417	.060
51	493.054	29,026.6	28,980.9	28,998.2	29,043.4	29,093.6	29,147.2	29,212.3	←	88,094.9	→	291,597.1	417.404	.047
53	493.054	←	58,020.6	→	29,002.7	29,044.9	29,089.2	29,148.7	29,209.0	29,282.3	29,357.5	29,444.5	291,599.4	417.408	.051
54	493.054												291,612.9	417.436	.079
55	493.054												291,588.2	417.386	.029
56	291.001	←			123,643.4			→	←	41,657.6	→	20,936.7	21,030.2	207,267.9	417.433	.076
57	291.001	20,555.7	20,538.7	20,572.5	20,616.8	20,667.0	20,740.0	20,787.0	20,861.5	20,941.0	21,029.1	207,309.3	417.575	.218
58	291.001	20,543.6	20,542.2	20,576.8	20,619.7	20,660.6	20,727.9	20,791.6	20,858.0	20,934.6	21,023.0	207,278.0	417.468	.111
59	291.001	20,546.7	20,539.5	20,583.8	20,632.5	20,673.2	20,734.2	20,798.2	20,869.7	20,948.7	21,028.8	207,355.3	417.733	.376
60	291.001											207,253.0	417.382	.025
62	366.801	23,710.6	23,699.9	23,732.4	23,774.0	23,821.9	23,884.6	23,947.5	24,016.4	24,093.9	24,180.6	238,861.8	417.303	−.054
63	366.801	23,702.8	23,699.3	23,731.4	23,765.2	23,818.3	23,880.7	23,947.4	24,015.3	24,088.1	24,178.3	238,826.8	417.208	−.149
67	495.653											292,688.8	417.418	.061
68	507.031											297,430.0	417.402	.045
69	507.031											297,413.0	417.368	.011
70	275.167											200,689.6	417.546	.189
71	275.167											200,629.6	417.329	−.028
72	275.167											200,620.5	417.296	−.061
73	498.832											293,974.5	417.335	−.022
74	498.832											293,965.5	417.317	−.040
75	498.832											293,958.1	417.302	−.055
77	258.324											193,595.3	417.308	−.049
78	258.324											193,594.7	417.306	−.051
80	268.054											197,658.5	417.319	−.038
81	268.054											197,652.1	417.295	−.062
82	268.054											197,672.1	417.370	.013
83	268.054											197,675.6	417.383	.026
84	475.116											284,074.3	417.329	−.028
85	475.116											284,073.6	417.328	−.029

Even-temperature interval 0°–100°. $Z]_0^{100}=85{,}794.5$ Int. joules. Mean value of $\alpha]_0^{100}=\alpha_m=417.357$ Int. joules per g.

NOTE.—The results of experiments 42 to 60, inclusive, were obtained in the earlier stages of the work and were given one-quarter the weight of the later results.

CALCULATION OF MEAN VALUE OF $\left[H-L-\frac{u}{u'-u}\right]_{100}^{200}$—Continued

Experiment No.	Mass of water M	Energy added for even temperature interval, $Q]_1^2$ Int. joules										$\Sigma Q]_1^2 = Q]_0^{100}$	$\alpha]_{100}^{200}$	Residual $\alpha]_{100}^{200}-\alpha_m$
		100°–110°	110°–120°	120°–130°	130°–140°	140°–150°	150°–160°	160°–170°	170°–180°	180°–190°	190°–200°			
	g													
86	475.903											294,320.1	416.817	−0.056
87	475.903	28,823.8	28,927.0	29,046.4	29,177.4	29,305.7								
88	475.903						29,459.1	29,624.3	29,798.0	29,988.4	30,197.2	294,347.3	416.874	.001
89	475.903	28,825.7	28,929.7	29,046.2	29,175.5	29,312.8	29,466.3	29,623.7	29,813.2	29,997.7	30,196.1	294,386.9	416.957	.084
90	475.903	28,825.4	28,928.8	29,047.9	29,170.2	29,314.5	29,461.4	29,627.2	29,805.0	29,983.1	30,208.7	294,372.2	416.927	.054
91	475.903											294,403.2	416.992	.119
95	267.764	20,144.5	20,251.9	20,365.8	20,493.7	20,633.6	20,763.0	20,950.2	21,129.4	21,326.3	21,535.9	207,594.3	416.929	.056
96	267.764	20,144.5	20,249.9	20,364.9	20,492.7	20,625.5	20,785.8	20,945.6	21,128.8	21,319.6	21,523.3	207,580.6	416.878	.005
97	267.764	20,150.3	20,247.5	20,369.0	20,493.8	20,631.5	20,795.4	20,933.6	21,122.2	21,315.9	21,531.3	207,590.5	416.915	.042
112	301.182	21,542.1	21,650.2	21,760.8	21,887.6	22,031.1	22,180.1	22,341.1	22,519.1	22,706.9	22,909.8	221,528.8	416.985	.062
113	410.025	26,077.0	26,183.7	26,297.6	26,423.3	26,567.4	26,714.0	26,874.1	27,052.5	27,238.4	27,436.9	266,864.9	416.827	−.046
114	410.025	26,066.3	26,173.2	26,291.8	26,417.9	26,559.3	26,706.4	26,873.3	27,045.7	27,238.1	27,440.4	266,812.4	416.698	−.175
115	419.333	26,457.4	26,565.8	26,681.6	26,812.7	26,951.9	←		137,246.6		→	270,716.0	416.758	−.115
116	388.753											258,010.8	416.859	−.014

Even-temperature interval 100°–200°. $Z]_{100}^{200}=95{,}955.6$ Int. joules. Mean value of $\alpha]_{100}^{200}=\alpha_m=416.873$ Int. joules per g.

CALCULATION OF MEAN VALUE OF $\left[H-L\frac{u}{u'-u}\right]_{200}^{270}$—Continued

Experiment No.	Mass of water, M	Energy added for even temperature interval, $Q]_1^2$ Int. joules							$\Sigma Q]_1^2 = Q[_{200}^{270}$	$a]_{200}^{270}$	Residual $a]_{200}^{270} - a_m$
		200°–210°	210°–220°	220°–230°	230°–240°	240°–250°	250°–260°	260°–270°			
173	292.871	23,464	23,701	23,957	24,233	24,511	24,825	25,152	169,843	289.276	0.199
174	408.332	28,243	28,473	28,715	28,986	29,257	29,555	29,882	203,111	288.952	−.122
175	414.265	28,486	28,718	28,954	29,226	29,515	29,805	30,133	204,837	288.980	−.097
176	279.315	22,900	[1] (23,131)	23,390	23,665	23,955	24,255	24,590	165,886	289.148	.071
177	413.267	28,472	28,675	28,941	29,193	29,472	29,773	30,087	204,613	289.136	.059
178	288.124	23,264	23,504	23,759	24,019	24,308	24,603	24,937	168,394	289.013	−.064
179	415.134	28,537	28,755	29,004	29,264	29,537	29,830	30,143	205,070	288.937	−.140
183	285.531	23,144	23,384	23,632	23,900	24,192	24,517	24,839	167,608	288.885	−.192
184	286.319	23,192	23,428	23,686	23,958	24,242	24,544	24,883	167,933	289.225	.148
185	418.892								206,249	289.159	.089
189	420.292	28,757	28,989	29,230	29,494	29,783	30,071	30,382	206,706	289.283	.206
190	277.212	22,832	23,054	23,312	23,577	23,881	24,192	24,500	165,348	289.401	.324
191	278.960	22,888	23,115	23,376	23,640	23,934	24,226	24,557	165,636	288.620	−.457
192	419.602		28,935								
195	421.532	28,796	29,024	29,272	29,534	29,814	30,102	30,429	206,971	289.061	−.016

Even temperature interval 200°–270°. $Z]_{200}^{270}$=85,122.5 Int. joules. Mean value of $a]_{200}^{270}=a_m$=289.077 Int. joules per g.

[1] Calculated from experiment 192.

The independent determinations of $\alpha]_0^{100}$, $\alpha]_{100}^{200}$, and $\alpha]_{200}^{270}$ are computed in Table 4 after summing up the total energy added in each entire experiment. The calculations for α_m and Z are made for these groups of data by least-square reduction, in the same manner as for the 10° groups in Table 3. The value for each individual experiment is then calculated and the deviations from the mean found.

The next step in Table 5 in the reduction is the adjustment of the 10° values of α, taking into account the results of the last calculation of the change in α between the temperatures of 0°, 100°, 200°, and 270° C. This adjustment consists in distributing the discrepancy between the 10° steps and the 100° or 70° steps proportionately, so as to make the adjusted values of the 10° steps add up to the same value as the overall. Having so adjusted the intermediate values, they are next summed up, giving as the result of this entire group of α experiments the table of values of $H-L\frac{u}{u'-u}$ at each multiple of 10° reckoned from 0° C.

TABLE 5.—*Adjustment of values of* $\left[H-L\frac{u}{u'-u}\right]$ *and assembly of final values reckoned from 0° C.*

Temperature interval (°C.)	Mean value of $\alpha]_1^2$	Adjusted value of $\alpha]_1^2$	Final adjusted value of $\alpha]_0^\theta$	Temperature
	Joules/g	*Joules/g*	*Joules/g*	*°C.*
0–10	41.984	41.989	41.989	10
10–20	41.802	41.808	83.797	20
20–30	41.708	41.714	125.511	30
30–40	41.704	41.709	167.220	40
40–50	41.698	41.704	208.924	50
50–60	41.683	41.688	250.612	60
60–70	41.683	41.689	292.301	70
70–80	41.685	41.690	333.991	80
80–90	41.666	41.671	375.662	90
90–100	41.690	41.695		
Total	417.303	417.357	417.357	100
0–100	417.357			
100–110	41.678	41.678	459.04	110
110–120	41.684	41.683	500.72	120
120–130	41.677	41.676	542.39	130
130–140	41.700	41.700	584.09	140
140–150	41.713	41.712	625.81	150
150–160	41.703	41.702	667.51	160
160–170	41.712	41.712	709.22	170
170–180	41.701	41.701	750.92	180
180–190	41.658	41.658	792.58	190
190–200	41.651	41.651		
Total	416.877	416.873	834.23	200
100–200	416.873			
200–210	41.503	41.519	875.75	210
210–220	41.391	41.407	917.16	220
220–230	41.338	41.354	958.51	230
230–240	41.302	41.318	999.83	240
240–250	41.242	41.258	1,041.09	250
250–260	41.127	41.143	1,082.23	260
260–270	41.062	41.078		
Total	288.966	289.077	1,123.31	270
200–270	289.077			

No adjustment for smoothing the trend of values has, up to this point, been introduced into the reduction. This will be undertaken under the head of formulation, to be described later.

2. GAMMA EXPERIMENTS

An example of the record of a single determination of γ, equal to $L\frac{u'}{u'-u}$, is given in Table 6. The total time of the experiment in this case is the time between the automatic shifting of the flow of vapor from the spill to the receiver, and the shifting to the next receiver, and applies to the electric heating, the pump energy, and the heat leak. The temperature readings are so distributed as to give the initial and final temperatures at these instants of starting and stopping the experiment. The readings of the thermometer with leads in the n position and of the thermoelements 1 to 5 were taken at 1-minute intervals during the experiment. These readings serve to determine the vraiation of temperature of the calorimeter during the experiment.

TABLE 6.—*Data sheet—determination of* $L\frac{u'}{u'-u}$

Experiment No. 273-A. November 16, 1929, at 270° C.
Observers: N. S. O., E. F. F., D. C. G.

Time	Thermometers. Bridge readings		Thermoelements		Electric power	
	2n	2r	t. e. 1-5	Regulating[1]	*I*	*E*
	Ohms	*Ohms*	*μv*	*μv*	*Amperes*	*Volts*
1.32.00						
1.32.30	51.8960		9.7			
1.32.40	51.8959		7.8			
1.32.50	51.8959		6.0			
1.33.00				(−3)		Start.
1.33.10		51.9027	4.0			
1.33.20		51.9028	3.6			
1.33.30		51.9027	3.8			
1.34.00	51.8960		5	−2		21.999
1.35.00	51.8958		8	(−1)	2.1549	
1.36.00	51.8964		10	1		21.997
1.37.00	51.8966		10	−1	2.1547	
1.38.00	51.8965		7	(−2)		21.996
1.39.00	51.8964		9	0	2.1547	
1.40.00	51.8964		12	(1)		21.996
1.41.00	51.8965		9	(−1)	2.1547	
1.42.00	51.8964		13	(2)		21.995
1.43.00	51.8971		13	(2)	2.1546	
1.44.00	51.8970		9	(−1)		21.995
1.45.00	51.8958		11	(1)	2.1545	
1.46.00	51.8957		13	(2)		21.993
1.47.00	51.8958		6	−4	2.1544	
1.48.00	51.8956		6	(−2)		21.992
1.49.00	51.8956		8	(−1)	2.1543	
1.50.00	51.8958		7	(−2)		21.991
1.51.00	51.8957		8	(−1)	2.1542	
1.52.00	51.8956		10	(0)		21.990
1.53.00	51.8956		10	1	2.1541	
1.54.00	51.8951		11	(1)		21.989
1.55.00	51.8951		7	(−2)	2.1541	
1.55.30	51.8954		6.8			
1.55.40	51.8957		6.4			
1.55.50	51.8958		6.9			
1.56.00				(−2)		Stop.
1.55.10		51.9028	8.7			
1.55.20		51.9028	9.2			
1.55.30		51.9030	9.8			

[1] Values in parentheses calculated from indications of t. e. 1-5.

Total heat-leak factor = −14 mv-min. Total time of experiment and electric heating = 1,380 seconds

A reduction, showing the calculation of γ, is given in Table 7. This reduction makes use of the formula:

$$\gamma_1 = \frac{1}{\Delta M}(Q_E + Q_P + Q_L - [Z + M_2\alpha]^2_1) + \frac{\Delta H'}{\Delta\theta}(\theta_1 - \theta_m)$$

in which Q_E, Q_P, and Q_L denote the amounts of energy added electrically, by the pump, and by heat leak, respectively. The term $[Z + M_2\alpha]^2_1$ expresses the energy correction for the difference of the final temperature of the calorimeter and its contents from the initial. The last term expresses the energy correction for variation in the temperature of steam withdrawn. This correction was found to be in every case less than 0.00001 of the whole, and has been omitted from the final calculation of γ.

TABLE 7.—*Computation–determination of* $L\frac{u'}{u'-u}$

EXPERMINENT No. 273-A

Temperature	Initial	Final
$(n+r)/2$ on bridge	51.89933	51.89925
Bridge correction	.01168	.01168
R_θ	51.91101	51.91093
$R_\theta - R_o$	26.30321	26.30313
$100\ (R_\theta - R_o)/(R_{100} - R_o)$	263.2320	263.2313
$0.01\theta(0.01\theta - 1)\delta$	6.7999	6.7998
Reference block temperature	270.0319	270.0311
Mean t. e. 1–5 (microvolts)	5.82	7.97
Mean t. e. 1–5 (degrees)	−.0189	−.0259
Temperature of calorimeter	270.0130	270.0052

CALCULATION OF ENERGY

Potentiometer	Current		Voltage
Mean reading	2.15447	Mean reading	21.9939
Potentiometer correction	.00020	Potentiometer correction	.0020
Correction for standard 0.01 ohm	−.00011	Correction for volt-box factor	.0073
Correction for volt-box current	−.00066	Voltage=E	22.0032
Current=I	2.15390		

Time of experiment=t=1,380 seconds.
Total electric energy=IEt ..... 65,401.9 joules.
Pump power=0.0477 watts.
Pump energy ..... 65.8 joules.
Total heat-leak factor=−14 microvolt-minutes.
Heat-leak coefficient=0.156 joule/microvolt-minute.
Heat leak ..... −2.2 joules.
Change in calorimeter temperature=−0.0068°
Factor for calorimeter temperature change=2,636 joules/degree.
Energy for calorimeter temperature change ..... 17.9 joules.

Total energy for evaporation ..... 65,483.4 joules.
Mass withdrawn=39.364 g.
$L\frac{u'}{u'-u}$ at 270.0130° ..... 1,663.54 joules/g.

The principal data from the gamma experiments are assembled in Table 8 and the computation of γ completed for the entire series.

TABLE 8.—*Principal data from γ experiments*

$$\gamma_1=\frac{1}{\Delta M}\{Q_E+Q_P+Q_L-[Z+M_2\alpha]_1^2\}+\frac{\Delta H'}{\Delta\theta}(\theta_1-\theta_m)$$

Experiment No.	Date	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Mass of vapor removed ΔM	Mass of water remaining M_2	Total electric energy Q_E	Pump energy Q_P	Heat leak Q_L	Energy correction for final temperature difference $-[Z+M_2\alpha]_1^2$	Entire energy added	Entire energy per gram γ_1	γ_θ corrected to even temperature	Residual $\gamma_\theta-\gamma_m$
		° *C.*	° *C.*	*Minutes*	*g*	*g*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*
228-A	May 25, 1929	99.956	99.941	60	28.631	360.9	64,434.8	226.2	−6.5	36.2	64,690.7	2,259.46	2,259.35	0.64
228-B	do	99.941	99.946	60	28.591	332.3	64,380.9	226.2	−8.9	−12.4	64,585.8	2,258.95	2,258.80	.09
228-C	do	99.946	99.941	60	28.576	303.7	64,345.3	226.2	−1.8	11.1	64,580.8	2,259.96	2,259.82	1.11
229-A	May 28, 1929	99.959	99.957	30	28.905	348.3	65,170.9	113.1	−1.2	40.9	65,323.7	2,259.94	2,259.83	1.12
229-B	do	99.957	99.962	30	28.903	319.4	65,189.4	113.1	−1.6	−11.7	65,289.3	2,258.91	2,258.80	.09
229-C	do	99.962	99.984	30	28.896	290.5	65,192.5	113.1	−5.9	−48.3	65,251.4	2,258.15	2,258.05	−.66
229-D	do	99.984	99.969	16	15.433	275.0	34,770.2	60.3	−1.1	32.4	34,861.8	2,258.91	2,258.87	.16
231-A	June 8, 1929	99.862	99.844	30	29.400	320.7	66,257.3	113.1	−2.0	42.4	66,410.8	2,258.87	2,258.50	−.21
231-B	do	99.844	99.833	30	29.395	291.3	66,230.4	113.1	3.4	23.0	66,369.9	2,257.86	2,257.45	−1.26
232-A	June 11, 1929	99.966	99.949	20	30.651	374.7	69,101.1	75.4	−5.5	42.3	69,213.3	2,258.11	2,258.02	−.69
232-B	do	99.949	99.949	21	32.165	342.5	72,558.9	79.2	1.3	−.2	72,639.2	2,258.33	2,258.19	−.52
232-C	do	99.949	99.938	20	30.634	311.9	69,095.4	75.4	1.9	25.9	69,198.6	2,258.88	2,258.74	.03
232-D	do	99.938	99.957	20	30.604	281.3	69,087.9	75.4	−1.1	−40.9	69,121.3	2,258.57	2,258.41	−.30
233-A	June 12, 1929	100.010	100.020	22	22.562	407.4	50,903.5	82.9	−.4	−25.5	50,960.5	2,258.69	2,258.72	.01
233-B	do	100.001	99.987	21	32.178	373.9	72,566.8	79.2	−2.5	36.7	72,680.2	2,258.69	2,258.69	−.02
233-C	do	99.987	99.982	20	30.646	343.3	69,112.4	75.4	−1.8	11.5	69,197.5	2,257.96	2,257.93	−.78
233-D	do	99.982	99.995	20	30.611	312.7	69,113.2	75.4	0	−30.3	69,158.3	2,259.26	2,259.21	.51
233-E	do	99.995	100.001	20	30.615	282.1	69,114.9	75.4	−3.3	−13.2	69,173.8	2,259.47	2,259.46	.75
234-A	June 13, 1929	99.986	100.000	40	39.074	311.3	88,105.2	150.8	−.4	−30.4	88,225.2	2,257.90	2,257.86	−.85

Even temperature 100°. $Z_{100}=956.3$ Int. joules/° C. $\alpha_{100}=4.169$ Int. joules per g° C. Mean value of $\gamma_{100}=\gamma_m=2{,}258.71$ Int. joules per g.

TABLE 8.—*Principal data from γ experiments*—Continued

$$\gamma_1=\frac{1}{\Delta M}\{Q_E+Q_P+Q_L-[Z+M_2\alpha]_1^2\}+\frac{\Delta H'}{\Delta\theta}(\theta_1-\theta_m)$$

Experiment No.	Date	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Mass of vapor removed ΔM	Mass of water remaining M_2	Total electric energy Q_E	Pump energy Q_P	Heat leak Q_L	Energy correction for final temperature difference $-[Z+M_2\alpha]_1^2$	Entire energy added	Entire energy per gram γ_1	γ_θ corrected to even temperature	Residual $\gamma_\theta-\gamma_m$
		° C.	° C.	Minutes	g	g	Int. joules	Int. joules	Int. joules	Int. joules	Int. joules	Int. joules/g	Int. joules/g	Int. joules/g
213-A	Apr. 22, 1929	129.939	129.949	30	29.708	367.8	64,536.6	153.6	−6.0	−24.7	64,659.5	2,176.50	2,176.33	−0.82
213-B	do	129.949	129.950	30	29.723	338.1	64,535.9	153.6	−4.0	−1.9	64,683.6	2,176.21	2,176.07	−1.07
225-A	May 22, 1929	129.915	129.908	30	31.207	375.1	67,802.1	109.8	7.7	16.0	67,935.6	2,176.93	2,176.69	−.46
225-B	do	129.908	129.924	30	31.151	343.9	67,813.0	109.8	−6.9	−37.8	67,878.1	2,179.00	2,178.74	1.59
225-C	do	129.924	129.912	30	31.206	312.7	67,789.9	109.8	7.6	26.9	67,934.2	2,176.96	2,176.75	−.40
225-D	do	129.912	129.932	30	31.143	281.6	67,740.3	109.8	3.0	−41.6	67,811.5	2,177.42	2,177.13	−.02
226-A	May 23, 1929	129.943	129.934	30	30.982	344.9	67,326.1	109.8	−2.9	22.6	67,455.6	2,177.25	2,177.09	−.06
226-B	do	129.934	129.944	30	30.963	313.9	67,315.7	109.8	−1.8	−23.9	67,399.8	2,176.79	2,176.60	−.55
226-C	do	129.944	129.931	30	30.953	283.0	67,258.9	109.8	−.5	28.7	67,396.9	2,177.39	2,177.23	.08
226-D	do	129.931	129.949	15	15.447	267.5	33,627.7	54.9	.1	−37.3	33,645.4	2,178.12	2,177.93	.78
227-A	May 24, 1929	129.944	129.934	60	31.037	347.0	67,343.2	219.6	−9.3	22.9	67,576.4	2,177.29	2,177.13	−.02
227-B	do	129.937	129.906	15	28.583	300.6	62,108.1	54.9	−1.4	69.6	62,231.2	2,177.21	2,177.03	−.12
227-C	do	129.906	129.917	15	28.527	272.0	62,076.4	54.9	−1.3	−23.2	62,106.8	2,177.12	2,176.87	−.28
235-A	June 14, 1929	129.986	129.986	20	32.752	379.3	71,267.5	73.2	−1.2	1.0	71,340.5	2,178.20	2,178.16	1.01
235-B	do	129.986	129.967	20	32.773	346.5	71,251.1	73.2	−1.0	44.1	71,367.4	2,177.63	2,177.59	.44
235-C	do	129.967	129.979	20	32.739	313.8	71,227.1	73.2	−.3	−26.8	71,273.2	2,177.01	2,176.92	−.23
235-D	do	129.979	129.976	20	32.728	281.0	71,189.7	73.2	−.7	7.3	71,269.5	2,177.63	2,177.57	.42
235-E	do	129.976	129.972	20	32.707	248.3	71,154.6	73.2	−1.0	7.7	71,234.5	2,177.96	2,177.90	.75
236-A	June 17, 1929	129.994	130.000	31	30.877	350.6	67,132.3	113.5	4.1	−15.5	67,234.4	2,177.49	2,177.47	.32
236-B	do	130.000	129.989	31	30.904	319.7	67,139.0	113.5	1.1	28.9	67,282.5	2,177.15	2,177.15	.00
236-C	do	129.989	129.985	31	30.885	288.8	67,145.6	113.5	−2.3	9.0	67,265.8	2,177.94	2,177.91	.76
236-D	do	129.985	130.000	31	30.877	257.8	67,128.4	113.5	4.9	−37.4	67,209.4	2,176.68	2,176.64	−.51
264-A	Oct. 12, 1929	130.021	130.015	30	29.317	372.9	63,681.2	109.8	−4.5	17.0	63,803.5	2,176.33	2,176.39	−.76
264-B	do	130.015	129.997	30	29.284	343.6	63,593.6	109.8	−4.9	42.7	63,741.2	2,176.66	2,176.70	−.45
264-C	do	129.997	130.015	30	29.207	314.4	63,530.6	109.8	−5.5	−41.4	63,593.5	2,177.34	2,177.33	.18
264-D	do	130.015	129.996	30	29.246	285.2	63,487.4	109.8	−5.7	41.2	63,632.7	2,175.58	2,175.62	−1.53
264-E	do	129.996	130.024	30	29.167	256.0	63,452.9	109.8	−5.1	−56.8	63,500.8	2,177.15	2,177.14	−.01
264-F	do	130.024	130.009	30	29.200	226.8	63,425.9	109.8	−2.8	28.7	63,561.6	2,176.77	2,176.84	−.31
264-G	do	130.009	129.989	30	29.189	197.6	63,402.2	109.8	−3.3	36.9	63,545.6	2,177.04	2,177.07	−.08

Even temperature 130°. Z_{130}=992.0 Int. joules per ° C. α_{130}=4.169 Int. joules per g ° C. Mean value of $\gamma_\theta=\gamma_m$=2,177.15 Int. joules per g.

246-A	July 24, 1929	150.004	149.997	20	19.876	294.8	42,054.4	71.8	2.0	15.8	42,144.0	2,120.35	2,120.36	.72
246-B	do	149.997	149.997	20	19.860	274.9	42,040.2	71.8	−.6	−1.1	42,110.3	2,120.36	2,120.35	.71
247-A	July 25, 1929	149.960	149.966	60	29.036	387.4	61,344.6	215.4	5.3	−15.3	61,550.0	2,119.78	2,119.66	.02
247-B	do	150.027	150.010	20	39.983	304.9	84,592.9	71.8	−.1	40.3	84,704.9	2,118.52	2,118.60	−1.04
247-C	do	150.010	149.999	21	42.193	262.8	89,334.7	75.4	3.5	22.7	89,436.3	2,119.70	2,119.73	.09
248-A	July 26, 1929	150.013	150.006	15	30.331	367.8	64,209.0	53.9	−.7	19.9	64,282.1	2,119.35	2,119.39	−.25
248-B	do	150.006	150.012	15	30.309	337.4	64,190.7	53.9	2.2	−14.8	64,232.0	2,119.24	2,119.26	−.38
248-C	do	150.006	150.010	15	30.304	276.7	64,173.6	53.9	−1.7	−10.4	64,215.4	2,119.04	2,119.06	−.58
248-D	do	150.010	150.010	15	30.296	246.4	64,160.2	53.9	3.0	1.2	64,218.3	2,119.70	2,119.73	.09
261-A	Sept. 26, 1929	149.943	149.976	30	31.091	367.1	65,909.7	97.8	−6.8	−83.7	65,917.0	2,120.13	2,119.96	.32
261-B	do	149.976	149.960	31	32.158	334.9	68,040.2	101.1	−9.4	37.9	68,169.8	2,119.84	2,119.77	.13
261-C	do	149.960	149.948	30	31.083	303.9	65,782.3	97.8	−3.6	28.4	65,904.9	2,120.29	2,120.17	.53
261-D	do	149.948	149.977	30	31.008	272.8	65,734.9	97.8	−8.5	−62.8	65,761.4	2,120.79	2,120.64	1.00
261-E	do	149.977	149.983	30	31.028	241.8	65,708.4	97.8	−7.0	−13.4	65,785.8	2,120.21	2,120.14	.50
261-F	do	149.983	149.985	30	31.027	210.8	65,697.4	97.8	−6.6	−3.4	65,785.2	2,120.26	2,120.21	.57
263-A	Oct. 11, 1929	149.959	149.978	30	29.457	327.6	62,356.5	107.7	−.4	−45.8	62,418.0	2,118.95	2,118.83	−.81
263-B	do	149.966	149.962	30	29.407	268.6	62,196.1	107.7	−1.1	9.4	62,312.1	2,118.95	2,118.85	−.79
263-C	do	149.962	149.961	30	29.371	239.2	62,111.2	107.7	−3.4	.6	62,216.1	2,118.28	2,118.17	−1.47
263-D	do	149.961	149.959	30	29.303	209.9	62,038.6	107.7	−1.6	4.0	62,148.7	2,120.90	2,120.79	1.15
263-E	do	149.959	149.959	30	29.287	180.6	61,961.4	107.7	−2.0	−.4	62,066.7	2,119.26	2,119.14	−.50

Even temperature 150°. Z_{150}=1,021 Int. joules per ° C. α_{150}=4.171 Int. joules per g ° C. Mean value of $\gamma_{150}=\gamma_m$=2,119.64 Int. joules per g.

249-A	July 30, 1929	169.989	170.010	15	30.777	354.7	63,345.9	52.7	5.0	−52.4	63,351.2	2,058.39	2,058.36	−.42
249-B	do	170.010	169.990	42	86.210	268.4	177,355.2	147.4	7.0	41.5	177,551.1	2,059.51	2,059.53	.75
249-C	do	169.990	169.998	15	30.775	237.6	63,356.2	52.7	4.4	−14.5	63,398.8	2,060.07	2,060.04	1.26
250-A	July 31, 1929	169.999	170.012	19	18.508	199.4	38,073.1	66.7	.9	−26.0	38,114.7	2,059.36	2,059.36	.58
251-A	Aug. 1, 1929	170.008	170.008	30	29.370	377.6	60,363.3	96.0	−2.1	−1.3	60,455.9	2,058.42	2,058.45	−.33
251-B	do	170.008	170.008	30	29.351	348.2	60,336.6	96.0	0	1.5	60,434.1	2,059.01	2,059.04	.26
251-C	do	170.008	170.000	30	29.342	318.9	60,296.5	96.0	−.4	17.6	60,409.7	2,058.81	2,058.84	.06
251-D	do	170.000	170.017	32	31.262	287.6	64,282.8	102.4	−.1	−37.4	64,347.7	2,058.34	2,058.34	−.44
251-E	do	170.017	170.000	30	29.328	258.3	60,242.8	96.0	3.5	38.1	60,380.4	2,058.80	2,058.85	.07
252-A	Aug. 2, 1929	170.036	170.018	30	30.465	375.8	62,563.2	105.3	−1.8	46.4	62,713.1	2,058.53	2,058.64	−.14
252-B	do	170.018	170.004	30	30.445	345.3	62,528.0	105.3	3.6	35.1	62,672.0	2,058.53	2,058.59	−.19
252-C	do	170.004	170.022	30	30.284	314.9	62,499.1	105.3	−3.1	−43.3	62,553.0	2,058.91	2,058.92	.14
252-D	do	170.022	170.008	30	30.407	284.5	62,460.2	105.3	−2.4	30.9	62,594.0	2,058.54	2,058.61	−.17
252-E	do	170.008	170.013	30	30.374	254.1	62,430.3	105.3	−.6	−10.8	62,521.2	2,058.48	2,058.51	−.27
252-F	do	170.013	170.014	30	30.372	223.8	62,403.8	105.3	2.1	−1.6	62,509.6	2,058.13	2,058.17	−.61
252-G	do	170.014	170.009	30	30.361	193.4	62,381.1	105.3	.4	9.5	62,496.3	2,058.44	2,058.48	−.30
252-H	do	170.009	170.008	33	33.382	160.0	68,596.3	115.8	3.1	1.7	68,716.9	2,058.50	2,058.53	−.25

Even temperature 170°. Z_{170}=1,055 Int. joules per ° C. α_{170}=4.171 Int. joules per g ° C. Mean value of $\gamma_{170}=\gamma_m$=2,058.78 Int. joules per g.

TABLE 8.—*Principal data from γ experiments*—Continued

$$\gamma_1=\frac{1}{\Delta M}\{Q_E+Q_P+Q_L-[Z+M_2\alpha]_1^2\}+\frac{\Delta H'}{\Delta\theta}(\theta_1-\theta_m)$$

Experiment No.	Date	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Mass of vapor removed ΔM	Mass of water remaining M_2	Total electric energy Q_E	Pump energy Q_P	Heat leak Q_L	Energy correction for final temperature difference $-[Z+M_2\alpha]_1^2$	Entire energy added	Entire energy per gram γ_1	γ_θ corrected to even temperature	Residual $\gamma_\theta-\gamma_m$
		° C.	° C.	Minutes	g	g	Int. joules	Int. joules	Int. joules	Int. joules	Int. joules	Int. joules/g	Int. joules/g	Int. joules/g
253-A	Aug. 3, 1929	200.023	200.030	15	30.034	274.1	58,767.8	46.5	0.3	−15.1	58,799.5	1,957.76	1,957.84	−0.12
253-B	do	200.030	200.026	20	40.055	230.0	78,318.4	62.0	2.6	8.2	78,391.2	1,957.09	1,957.20	−.76
253-C	do	200.026	200.012	15	30.032	204.0	58,717.2	46.5	.9	26.6	58,791.2	1,957.62	1,957.71	−.25
254-A	Aug. 5, 1929	200.000	200.008	31	32.908	311.9	64,374.5	96.1	1.0	−20.5	64,451.1	1,958.52	1,958.52	.56
254-B	do	200.008	200.012	29	30.790	281.1	60,184.7	89.9	.9	−8.2	60,267.3	1,957.37	1,957.39	−.57
254-C	do	200.012	200.008	30	31.823	249.5	62,233.0	93.0	.3	9.3	62,335.6	1,958.82	1,958.86	.90
254-D	do	200.008	199.997	30	31.836	217.4	62,204.2	93.0	.6	21.4	62,319.2	1,957.51	1,957.53	−.43
254-E	do	199.997	200.006	30	31.796	185.6	62,179.4	93.0	−.1	−17.2	62,255.1	1,957.95	1,957.94	−.02
255-A	Aug. 7, 1929	199.991	199.978	30	31.486	349.4	61,526.4	93.0	−.6	34.2	61,653.0	1,958.11	1,958.08	.12
255-B	do	199.978	199.980	30	31.447	317.9	61,488.5	93.0	−1.3	−3.9	61,576.3	1,958.10	1,958.02	.06
255-C	do	199.980	199.979	30	31.426	286.5	61,448.6	93.0	−2.8	1.6	61,540.4	1,958.26	1,958.19	.23
255-D	do	199.979	199.981	30	31.399	255.1	61,407.7	93.0	.8	−3.5	61,498.0	1,958.60	1,958.53	.57
255-E	do	199.981	199.979	30	31.381	223.7	61,363.5	93.0	−1.0	−2.9	61,452.6	1,958.27	1,958.20	.24
255-F	do	199.979	199.984	10	10.454	213.2	20,444.5	30.4	−.4	−10.4	20,464.1	1,957.54	1,957.47	−.49
Even temperature 200°. Z_{200}=1,119 Int. joules per ° C. α_{200}=4.159 Int. joules per g ° C. Mean value of $\gamma_{200}=\gamma_m$=1,957.96 Int. joules per g.														
256-A	Aug. 8, 1929	219.974	219.986	30	31.248	359.1	58,783.8	91.2	5.9	−29.7	58,851.2	1,883.36	1,883.26	−.16
256-B	do	219.986	220.001	30	31.214	327.9	58,734.7	91.2	5.9	−37.8	58,788.1	1,883.39	1,883.34	−.08
256-C	do	220.001	220.004	31	32.226	295.7	60,626.3	94.2	.5	−7.4	60,713.6	1,883.99	1,883.99	.57
256-D	do	220.004	219.995	30	31.174	264.5	58,606.6	91.2	−1.1	20.6	58,717.3	1,883.53	1,883.55	.13
256-E	do	219.995	220.000	30	31.122	233.4	58,552.7	91.2	−1.7	−12.2	58,630.0	1,883.88	1,883.86	.44
256-F	do	220.000	220.001	30	31.110	202.3	58,493.0	91.2	−.1	−.8	58,583.3	1,883.10	1,883.10	−.32
256-G	do	220.001	219.992	32	33.157	169.1	62,347.1	97.3	.5	15.7	62,460.6	1,883.78	1,883.78	.36
257-A	Aug. 9, 1929	218.207	218.208	30	30.958	315.9	58,433.7	91.2	1.6	−2.2	68,524.3	1,890.44	1,883.50	.08
257-B	do	218.208	218.213	31	31.964	283.9	60,337.6	94.2	.5	−11.5	60,420.8	1,890.28	1,883.35	−.07
257-C	do	218.213	218.204	30	30.926	253.0	58,339.1	91.2	.8	19.7	58,450.8	1,890.02	1,883.10	−.32
257-D	do	218.204	218.202	30	30.880	221.1	58,280.1	91.2	.1	5.0	58,376.4	1,890.42	1,883.46	.04
257-E	Aug. 9, 1929	218.202	218.218	30	30.836	191.3	58,229.9	91.2	2.3	−31.2	58,292.2	1,890.39	1,883.43	.01
257-F	do	218.218	218.214	19	19.524	171.7	36,852.3	57.8	2.1	6.2	36,918.4	1,890.92	1,883.98	.56
257-G	do	218.214	218.206	13	13.355	158.4	25,203.0	39.5	2.4	15.3	25,260.2	1,891.44	1,884.48	1.06

258-A	Aug. 10, 1929	220.010	220.000	15	29.149	345.0	54,820.2	45.6	.5	25.7	54,892.0	1,883.15	1,883.19	−.23
258-B	do	220.000	220.011	15	29.127	315.9	54,811.7	45.6	2.5	−25.5	54,834.3	1,882.59	1,882.59	−.83
258-C	do	220.011	220.015	15	29.119	286.8	54,801.1	45.6	1.7	−11.1	54,837.3	1,883.21	1,883.25	−.17
258-D	do	220.015	220.016	15	29.116	257.7	54,794.8	45.6	1.3	−1.8	54,839.9	1,883.50	1,883.56	.14
258-E	do	220.016	220.011	16	31.067	226.6	58,442.9	48.6	2.4	10.7	58,504.6	1,883.18	1,883.24	−.18
258-F	do	220.011	220.010	15	29.119	197.5	54,786.0	45.6	1.6	2.4	54,835.6	1,883.16	1,883.20	−.22
258-G	do	220.100	220.010	15	29.104	168.4	54,786.4	45.6	2.0	.9	54,834.9	1,884.10	1,884.14	.72
259-A	Aug. 12, 1929	220.008	220.005	60	30.388	373.2	57,044.4	182.4	−2.2	7.3	57,231.9	1,883.37	1,883.40	−.02
259-B	do	220.005	219.999	60	30.429	342.7	57,037.1	182.4	1.9	14.0	57,235.4	1,880.95	1,880.97	−2.45
259-C	do	219.999	220.012	60	30.357	312.4	57,030.3	182.4	4.0	−30.8	57,185.9	1,883.78	1,883.78	.36
259-D	do	220.012	220.018	60	30.365	282.0	57,020.8	182.4	3.4	−13.3	57,193.3	1,883.53	1,883.58	.16
259-E	do	220.021	220.005	60	30.366	220.1	56,986.8	182.4	−1.6	34.7	57,202.3	1,883.76	1,883.84	.42
Even temperature 220° Z_{220}=1,169 Int. joules per ° C. α_{220}=4.138 Int. joules per g ° C. Mean value of $\gamma_{220}=\gamma_m$=1,883.42 Int. joules per g.													
265-A	Oct. 23, 1929	250.005	250.023	30	33.462	322.6	58,818.2	96.9	−9.4	−45.8	58,859.9	1,759.01	1,759.03	.15
265-B	do	250.023	250.011	31	34.610	288.0	60,760.7	100.1	−10.8	27.6	60,877.6	1,758.96	1,759.06	.18
259-C	do	250.016	250.004	31	34.594	219.9	60,717.7	100.1	−7.8	27.7	60,837.7	1,758.62	1,758.69	−.19
266-A	Oct. 24, 1929	250.027	249.999	32	34.514	329.6	60,534.2	103.4	−12.3	74.0	60,699.3	1,758.69	1,758.81	−.07
259-B	do	250.034	250.037	30	32.227	240.4	56,592.1	96.9	−6.8	−5.8	56,676.4	1,758.66	1,758.81	−.07
Even temperature 250°. Z_{250}=1,259 Int. joules per °C. α_{250}=4.120 Int. joules per g °C. Mean value of $\gamma_{250}=\gamma_m$=1,758.88 Int. joules per g.													
269-A	Nov. 12, 1929	269.968	269.996	28	29.112	341.4	48,513.1	88.5	−1.8	−76.0	48,523.8	1,666.80	1,666.64	1.43
269-B	do	269.996	269.950	30	31.323	310.1	51,958.1	94.8	−8.0	117.9	52,162.8	1,665.32	1,665.30	.09
269-C	do	269.950	269.985	30	31.225	278.9	51,943.4	94.8	−3.0	−85.2	51,950.0	1,663.73	1,663.48	−1.73
269-D	do	269.985	269.975	30	31.221	247.7	51,925.4	94.8	−5.3	22.7	52,037.6	1,666.75	1,666.68	1.47
269-E	do	269.975	269.997	30	31.189	216.5	51,909.5	94.8	−8.0	−49.0	51,947.3	1,665.56	1,665.44	.23
270-A	Nov. 13, 1929	270.025	270.039	30	30.623	329.8	50,949.0	94.8	−8.7	−37.5	50,997.6	1,665.34	1,665.46	.25
270-B	do	270.039	270.010	30	30.667	299.1	50,922.7	94.8	−10.4	74.8	51,081.9	1,665.70	1,665.89	.68
270-C	do	270.010	270.035	30	30.639	268.5	50,908.5	94.8	−12.5	−60.7	50,930.1	1,662.26	1,662.31	−2.90
270-D	do	270.035	270.016	30	30.616	237.9	50,902.1	94.8	−14.7	41.7	51,023.9	1,666.58	1,666.75	1.54
270-E	do	269.998	270.020	30	30.619	186.8	50,894.9	94.8	−11.2	−54.2	50,934.3	1,663.49	1,663.48	−1.73
270-F	do	270.020	269.974	20	20.433	166.4	33,917.8	63.2	−9.7	92.0	34,063.3	1,667.07	1,667.17	1.96
271-A	Nov. 14, 1929	270.045	270.006	31	32.365	350.9	53,676.4	98.0	−2.2	108.4	53,880.6	1,664.78	1,665.00	−.21
271-B	do	270.006	270.012	30	31.250	319.7	51,925.1	94.8	6.9	−17.1	52,009.7	1,664.31	1,664.34	−.87
271-C	do	270.012	270.006	30	31.264	288.4	51,904.3	94.8	−10.6	15.1	52,003.6	1,663.37	1,663.43	−1.78
271-D	do	270.006	270.002	31	32.257	256.2	53,618.4	98.0	5.1	10.9	53,732.4	1,665.76	1,665.79	.58
271-E	do	270.002	269.999	30	31.188	224.9	51,868.6	94.8	−8.1	6.1	51,961.4	1,666.07	1,666.08	.87
272-A	Nov. 15, 1929	270.047	270.036	60	31.410	364.3	52,090.9	189.6	−12.0	30.5	52,299.0	1,665.04	1,665.27	.06
272-B	do	270.036	269.995	60	31.433	332.8	52,016.2	189.6	−1.2	110.6	52,315.2	1,664.34	1,664.52	−.69
272-C	do	270.039	270.012	43	22.441	279.0	37,223.4	135.9	−18.4	70.0	37,410.9	1,667.07	1,667.26	2.05
273-A	Nov. 16, 1929	270.013	270.005	23	39.359	319.4	65,401.9	72.7	−2.2	17.9	65,490.3	1,663.92	1,663.98	−1.23
273-B	do	270.005	269.999	22	37.604	281.8	62,528.8	69.5	−3.7	14.9	62,609.5	1,664.97	1,664.99	−.22
273-C	do	269.999	269.996	20	34.120	247.6	56,772.0	63.2	−2.7	8.2	56,840.7	1,665.91	1,665.91	.70
273-D	do	269.996	270.014	20	34.104	213.5	56,738.4	63.2	−1.9	−41.2	56,758.5	1,664.28	1,664.26	−.95
273-E	do	270.014	270.006	16	27.288	186.2	45,388.8	50.6	−2.7	17.1	45,453.8	1,665.71	1,665.78	.57
273-F	do	270.006	270.021	15	25.572	160.7	42,561.2	47.4	−.3	−28.6	42,579.7	1,665.09	1,665.11	−.10
Even temperature 270°. Z_{270}=1,328 Int. joules per °C. α_{270}=4.100 Int. joules per g °C. Mean value of $\gamma_{270}=\gamma_m$=1,665.21 Int. joules per g.													

3. BETA EXPERIMENTS

An example of the record of a single determination of β, equal to $L\frac{u}{u'-u}$, is given in Table 9. This is similar to the record for a gamma experiment, but differs from it in that the total time of the experiment over which the energy account is kept is longer than the time of electric heating and removal of liquid.

TABLE 9.—*Data sheet—determination of* $L\frac{u}{u'-u}$

Experiment No. 207-C, February 21, 1929, at 240° C.

Observers: N. S. O., H. F. S., E. F. F.

Time	Thermometers—Bridge readings		Thermoelements		Electric power	
	2n	2r	t. e. 1-5	Regulating[1]	I	E
	Ohms	*Ohms*	*μv.*	*μv.*	*Amperes*	*Volts*
2.28.00	49.0813		6.1			
2.28.10	49.0814		6.1			
2.28.20	49.0815		6.2			
2.28.30				(1)		
2.28.40		49.0878	6.1			
2.28.50		49.0880	6.2			
2.29.00		49.0879	6.0			On.
2.29.30	49.0814		7	(1)		
2.30.00		49.0877	8	(2)	0.97450	
2.30.30	49.0811		5	(0)		
2.31.00		49.0873	5	1		9.9160
2.31.30			6	(0)		
2.32.00		49.0871	6	(0)	.97450	
2.32.30	49.0807		4	(−1)		
2.33.00		49.0870	5	(0)		Off 9.9164
2.33.30	49.0806		2.2			
2.33.40	49.0805		2.0			
2.33.50	49.0806		2.1			
2.34.00				(−2)		
2.34.10		49.0870	2.0			
2.34.20		49.0871	2.1			
2.34.30		49.0870	1.9			

[1] Values in parentheses calculated from indications of t. e. 1-5.

Total heat-leak factor=+3 microvolt-minutes.
Total time of experiment, 2.28.30 to 2.34.00=330 seconds.
Total time of electric heating 2.29.00 to 2.33.00=240 seconds.

Table 10 shows the calculation of β. This calculation makes use of the following formula:

$$\beta_1=\frac{1}{\Delta M}(Q_E+Q_P+Q_L-[Z+M_2\alpha]^2{}_1)+\frac{\Delta H}{\Delta\theta}(\theta_1-\theta_m)$$

TABLE 10.—*Computation—determination of* $L\frac{u}{u'-u}$

EXPERIMENT NO. 207-C

Temperature	Initial	Final
$(n+r)/2$ on bridge	49.08465	49.08380
Bridge correction	.00969	.00969
R_θ	49.09434	49.09349
$R_\theta-R_0$	23.48654	23.48569
$100\ (R_\theta-R_0)/(R_{100}-R_0)$	235.0439	235.0354
$0.01\theta\ (0.01\theta-1)\delta$	4.9774	4.9768
Reference block temperature	240.0123	240.0122
Mean t. e. 1–5 (microvolts)	6.12	2.05
Meant t. e. 1–5 (degrees)	.0203	.0068
Temperature of calorimeter	240.0010	240.0054

CALCULATION OF ENERGY

Potentiometer	Current		Voltage
Mean reading	0.97452	Mean reading	9.9162
Potentiometer correction	.00002	Potentiometer correction	.0002
Correction for standard 0.01 ohm	−.00005	Correction for volt-box factor	.0033
Correction for volt-box current	−.00030	Voltage=E	9.9197
Current=I	0.97419		

Time of electric heating=240 seconds.
Total electric energy=IEt ..... 2,319.3 joules.
Total time of experiment=330 seconds.
Pump power=0.0748 watts.
Pump energy ..... 24.7 joules.
Total heat-leak factor=+3 microvolt-minutes.
Heat-leak coefficient=0.142 joules/microvolt-minute.
Heat leak ..... .4 joules.
Change in calorimeter temperature+0.004°.
Factor for calorimeter temperature change=2,949 joules/degree.
Energy for calorimeter temperature change ..... −11.8 joules.

Total energy supplied ..... 2,332.6 joules.
Mass withdrawn=62.722 g.
Energy per gram ..... 37.190 joules/g.
Mean bridge reading during experiment=48.08421.
Mean reference block temperature during experiment=240.0169°.
Mean t. e. 1–5 during experiment=5.78 microvolts=0.0192°.
Mean calorimeter temperature during experiment=239.9977°.
Heat content at initial minus heat content at mean (H_1-H_m) ..... 0.016 joules/g.

$L\frac{u}{u'-u}$ at 240.0010° ..... 37.206 joules/g.

The principal data from the beta experiments are assembled in Table 11 and the computation of β completed for the entire series.

TABLE 11.—*Principal data from β experiments*

$$\beta_1=\frac{1}{\Delta M}\{Q_E+Q_P+Q_L-[Z+M_{2a}]^2_1\}+\frac{\Delta H}{\Delta\theta}(\theta_1-\theta_m)$$

Experiment No.	Date	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Mass of water removed ΔM	Mass of water remaining M_2	Total electric energy Q_E	Pump energy Q_P	Heat leak Q_L	Energy correction for final temperature difference, $-[Z+M_{2a}]^2_1$	Total energy added	Energy added per gram removed	$\theta_1-\theta_m$	Correction for temperature variation $\frac{\Delta H}{\Delta\theta}\times(\theta_1-\theta_m)$	Correction to even temperature	β corrected to even temperature
		° C.	° C.	*Minutes*	*g*	*g*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	*Int. joules*	° C.	*Int. joules per g*	*Int. joules per g*	*Int. joules per g*
180-A	Dec. 28, 1928	100.000	100.007	19.000	189.123	230.5	178.6	100.3	−1.4	−13.4	264.1	1.396	−0.002	−0.008	0.000	1.388
182-A	Dec. 31, 1928	100.019	100.018	14.000	140.217	278.3	121.8	73.9	−1.5	2.1	196.3	1.400	.002	.008	−.001	1.407
204-A	Feb. 18, 1929	99.827	99.830	9.333	118.829	301.9	132.3	49.3	−1.3	−6.6	173.7	1.462	−.009	−.038	.008	1.432
Even temperature 100°. $\frac{\Delta H}{\Delta\theta}$=4.22 Int. joules per g° C. Z_{100}=956 Int. joules per ° C. α_{100}=4.169 Int. joules per g° C. Mean value of β_{100}=1.409 Int. joules per g.																
207-A	Feb. 21, 1929	110.004	109.997	3.500	69.719	352.0	102.2	18.3	−.8	15.3	135.0	1.936	.001	.004	.000	1.941
207-B	do	110.060	110.047	3.500	77.187	274.8	102.6	18.3	−.3	27.9	148.5	1.924	.009	.038	−.004	1.958
Even temperature 110°. $\frac{\Delta H}{\Delta\theta}$=4.23 Int. joules per g° C. Z_{110}=967 Int. joules per ° C. α_{110}=4.168 Int. joules per g° C. Mean value of β_{110}=1.950 Int. joules per g.																
199-A	Feb. 12, 1929	120.011	120.016	14.333	130.590	298.1	279.4	74.2	−2.1	−11.1	340.4	2.607	.003	.013	−.001	2.623
199-B	do	120.093	120.115	14.333	120.155	303.0	294.2	74.2	.3	−49.3	319.4	2.658	−.014	−.060	−.007	2.591
203-A	Feb. 16, 1929	120.044	120.044	9.333	77.736	346.1	154.0	48.3	−.7	.0	201.6	2.593	.012	.051	−.004	2.640
203-B	do	120.114	120.113	10.333	80.539	265.6	154.9	53.5	−.4	2.1	210.1	2.609	−.001	−.004	−.009	2.596
Even temperature 120°. $\frac{\Delta H}{\Delta\theta}$=4.25 Int. joules per g° C. Z_{120}=979 Int. joules per ° C. α_{120}=4.168 Int. joules per g° C. Mean value of β_{120}=2.613 Int. joules per g.																
205-A	Feb. 19, 1929	129.991	130.006	9.333	57.631	363.8	195.3	47.8	−.2	−38.6	204.3	3.545	−.009	−.038	.001	3.508
205-B	do	130.067	130.059	8.667	80.403	283.4	220.5	44.4	−1.3	18.9	282.5	3.514	.004	.017	−.007	3.524
206-A	Feb. 20, 1929	130.016	130.050	3.500	75.196	341.1	215.3	17.9	−.8	25.6	258.0	3.431	.008	.034	−.002	3.463
206-B	do	130.071	130.075	3.500	64.235	281.9	215.5	17.9	.0	−9.8	223.6	3.481	−.004	−.017	−.007	3.457
Even temperature 130°. $\frac{\Delta H}{\Delta\theta}$=4.27 Int. joules per g° C. Z_{130}=992 Int. joules per ° C. α_{130}=4.169 Int. joules per g° C. Mean value of β_{130}=3.488 Int. joules per g.																

200-A	Feb. 13, 1929	139.964	139.969	8.333	58.429	370.5	239.3	42.2	.3	−12.8	269.0	4.604	.001	.004	.004	4.612
201-A	Feb. 14, 1929	140.050	140.058	7.333	196.732	228.5	876.5	37.2	−.3	−15.7	897.7	4.563	−.004	−.017	−.006	4.540
202-A	Feb. 15, 1929	140.011	140.009	9.333	79.570	339.3	309.4	47.3	−1.1	4.8	360.4	4.529	.003	.013	−.001	4.541
202-B	do	140.097	140.105	9.333	73.166	266.1	309.5	47.3	−1.1	−16.9	338.8	4.631	−.008	−.034	−.012	4.585

Even temperature 140°. $\frac{\Delta H}{\Delta\theta}$=4.29 Int. joules per g ° C. Z_{140}=1,006 Int. joules per ° C. α_{140}=4.171 Int. joules per g ° C.

Mean value of β_{140}=4.570 Int. joules per g.

177-A	Dec. 21, 1928	150.101	150.106	19.000	152.916	261.7	824.4	95.4	.0	−10.6	909.2	5.946	.000	.000	−.015	5.931
198-A	Feb. 9, 1929	149.913	149.918	14.333	135.999	285.7	745.8	72.0	−.8	−11.1	805.9	5.926	−.003	−.013	.013	5.926
209-A	Feb. 25, 1929	149.986	149.979	5.500	56.233	365.2	285.8	27.6	−.6	16.5	329.3	5.856	−.002	−.009	.002	5.849
209-B	do	150.046	150.051	5.500	58.587	306.6	329.9	27.6	−.2	−10.6	346.7	5.918	−.002	−.009	−.007	5.902

Even temperature 150°. $\frac{\Delta H}{\Delta\theta}$=4.32 Int. joules per g ° C. Z_{150}=1,021 Int. joules per ° C. α_{150}=4.171 Int. joules per g ° C.

Mean value of β_{150}=5.902 Int. joules per g.

211-A	Feb. 27, 1929	159.936	159.938	4.500	66.586	359.7	482.2	22.4	−.4	−4.6	499.6	7.503	−.002	−.009	−.012	7.509
211-B	do	159.997	159.996	4.500	72.729	287.1	521.9	22.4	−.4	2.0	545.9	7.506	.001	.004	−.001	7.506

Even temperature 160°. $\frac{\Delta H}{\Delta\theta}$=4.35 Int. joules per g ° C. Z_{160}=1,037 Int. joules per ° C. α_{160}=4.171 Int. joules per g ° C.

Mean value of β_{160}=7.508 Int. joules per g.

203-B	Feb. 16, 1929	169.990	169.993	9.333	61.854	356.2	548.4	45.9	−.6	−7.6	586.1	9.476	−.001	−.004	.002	9.474
203-C	do	170.053	170.041	9.333	71.437	284.7	606.3	45.9	−1.1	26.9	678.0	9.491	.007	.031	−.011	9.511

Even temperature 170°. $\frac{\Delta H}{\Delta\theta}$=4.38 Int. joules per g ° C. Z_{170}=1,055 Int. joules per ° C. α_{170}=4.171 Int. joules per g ° C.

Mean value of β_{170}=9.492 Int. joules per g.

168-A	Nov. 19, 1928	200.232	200.233	24.000	128.131	296.4	2,184.0	114.5	.8	−2.3	2,297.0	17.927	−.004	−.018	−.081	17.828
171-A	Nov. 22, 1928	200.774	200.782	22.000	140.844	285.5	2,466.3	104.9	2.1	−18.4	2,554.9	18.140	−.001	−.005	−.272	17.863
173-A	Dec. 17, 1928	200.632	200.641	20.000	121.718	292.9	2,128.1	95.4	.8	−21.1	2,203.2	18.101	−.007	−.032	−.222	17.847
176-A	Dec. 20, 1928	200.215	200.230	19.000	134.847	279.4	2,355.7	90.6	4.8	−34.2	2,416.9	17.923	.000	.000	−.075	17.848
178-A	Dec. 26, 1928	200.148	200.157	20.000	132.637	288.2	2,282.3	95.4	2.6	−20.8	2,359.5	17.789	.000	.000	−.052	17.737
183-A	Jan. 2, 1929	200.172	200.180	18.625	133.674	286.4	2,313.6	88.8	−4.1	−18.4	2,379.9	17.804	.005	.023	−.060	17.767
184-A	Jan. 3, 1929	200.147	200.150	19.333	133.349	285.6	2,299.6	92.2	−1.9	−6.9	2,383.0	17.870	.003	.014	−.052	17.832
190-A	Jan. 23, 1929	200.152	200.163	19.000	139.456	277.2	2,447.7	64.8	−.1	−26.1	2,486.3	17.829	.007	.032	−.053	17.808
191-A	Jan. 24, 1929	200.250	200.255	19.333	140.607	279.0	2,436.5	92.2	.8	−11.4	2,518.1	17.909	.003	.014	−.088	17.835
196-A	Feb. 1, 1929	200.050	200.049	20.000	134.792	287.0	2,309.1	95.4	−1.3	2.3	2,405.5	17.846	.003	.014	−.018	17.842

Even temperature 200°. $\frac{\Delta H}{\Delta\theta}$=4.51 Int. joules per g ° C. Z_{200}=1,119 Int. joules per ° C. α_{200}=4.159 Int. joules per g ° C.

Mean value of β_{200}=17.821 Int. joules per g.

TABLE 11.—*Principal data from β experiments*—Continued

$$\beta_1=\frac{1}{\Delta M}\{Q_E+Q_P+Q_L-[Z+M_{2c}]^2_1\}+\frac{\Delta H}{\Delta\theta}(\theta_1-\theta_m)$$

Experiment No.	Date	Initial temperature θ_1	Final temperature θ_2	Total time of experiment	Mass of water removed ΔM	Mass of water remaining M_2	Total electric energy Q_E	Pump energy Q_P	Heat leak Q_L	Energy correction for final temperature difference, $-[Z+M_{2c}]^2_1$	Total energy added	Energy added per gram removed	$\theta_1-\theta_m$	Correction for temperature variation $\frac{\Delta H}{\Delta\theta}\times(\theta_1-\theta_m)$	Correction to even temperature	β corrected to even temperature
		° C.	° C.	Minutes	g	g	Int. joules	Int. joules	Int. joules	Int. joules	Int. joules	Int. joules	° C.	Int. joules per g	Int. joules per g	Int. joules per g
204-B	Feb. 18, 1929	219.920	219.923	14.000	134.034	284.4	3,424.8	65.4	0.5	−7.0	3,483.7	25.991	0.001	0.005	0.038	26.034
205-C	Feb. 19, 1929	220.050	220.050	6.667	141.309	273.6	3,647.9	31.1	−.1	.7	3,679.6	26.039	.004	.018	−.024	26.033
Even temperature 220°. $\frac{\Delta H}{\Delta\theta}$=4.62 Int. joules per g ° C. Z_{220}=1,169 Int. joules per ° C. α_{220}=4.138 Int. joules per g. ° C.																
Mean value of β_{220}=26.034 Int. joules per g.																
206-C	Feb. 20, 1929	229.927	229.940	4.000	57.261	359.0	1,803.9	18.5	−.7	−35.9	1,785.8	31.187	−.001	−.005	.039	31.221
206-D	do	229.992	229.975	3.500	61.843	297.1	1,867.7	16.2	.1	42.2	1,926.2	31.147	.010	.047	.004	31.198
Even temperature 230°. $\frac{\Delta H}{\Delta\theta}$=4.68 Int. joules per g ° C. Z_{230}=1,197 Int. joules per ° C. α_{230}=4.134 Int. joules per g. ° C.																
Mean value of β_{230}=31.210 Int. joules per g.																
192-A	Jan. 25, 1929	239.986	240.007	15.333	62.817	356.8	2,323.1	70.1	1.1	−56.7	2,337.6	37.213	−.007	−.033	.009	37.189
192-B	do	240.089	240.107	14.333	68.444	288.4	2,525.0	65.5	1.9	−45.8	2,546.6	37.207	−.007	−.033	−.055	37.119
207-C	Feb. 21, 1929	240.001	240.005	5.500	62.713	354.9	2,319.3	25.1	.4	−11.8	2,333.0	37.201	.003	.014	−.001	37.214
207-D	do	240.054	240.063	5.500	65.386	289.5	2,425.4	25.1	−.2	−22.7	2,427.6	37.127	.013	.062	−.033	37.156
Even temperature 240°. $\frac{\Delta H}{\Delta\theta}$=4.76 Int. joules per g ° C. Z_{240}=1,227 Int. joules per ° C. α_{240}=4.129 Int. joules per g. ° C.																
Mean value of β_{240}=37.170 Int. joules per g.																
208-A	Feb. 23, 1929	249.763	249.779	5.500	65.034	355.5	2,865.8	24.9	.6	−44.1	2,847.2	43.780	−.002	−.010	.169	43.939
208-B	do	249.839	249.831	5.500	67.912	287.6	2,928.6	24.9	.9	19.3	2,973.7	43.788	.009	.044	.115	43.947
Even temperature 250°. $\frac{\Delta H}{\Delta\theta}$=4.85 Int. joules per g ° C. Z_{250}=1,259 Int. joules per ° C. α_{250}=4.120 Int. joules per g. ° C.																
Mean value of β_{250}=43.943 Int. joules per g.																

172-A	Nov. 23, 1928	270.190	270.211	33.000	140.721	285.4	8,523.8	145.9	2.8	−52.5	8,620.0	61.256	−.009	−.046	−.189	61.021
175-A	Dec. 19, 1928	270.232	270.251	25.000	139.687	274.6	8,477.8	110.5	8.4	−46.7	8,550.0	61.208	.000	.000	−.231	60.977
177-B	Dec. 21, 1929	270.200	270.192	25.000	137.092	276.2	8,235.5	110.5	5.3	19.7	8,371.0	61.061	−.004	−.020	−.199	60.842
181-A	Dec. 29, 1928	269.974	269.983	25.000	142.219	277.4	8,564.9	110.5	2.3	−22.2	8,655.5	60.860	.011	.056	.026	60.927
185-A	Jan. 4, 1929	270.598	270.597	10.333	34.207	384.7	2,045.8	45.7	−.8	2.9	2,093.6	61.204	.003	.015	−.595	60.624
187-A	Jan. 18, 1929	270.347	270.295	11.000	29.485	385.3	1,598.9	48.6	−2.2	151.4	1,796.7	60.936	.034	.173	−.345	60.764
187-B	do	270.387	270.371	9.000	22.994	362.3	1,332.4	39.8	2.2	45.1	1,419.5	61.733	.021	.108	−.385	61.456
188-A	Jan. 19, 1929	270.353	270.351	8.000	32.901	329.4	1,984.2	35.4	1.2	5.4	2,026.2	61.585	.003	.015	−.351	61.249
188-B	do	270.441	270.453	8.000	31.475	298.0	1,936.3	35.4	3.1	−30.6	1,944.2	61.770	.003	.015	−.439	61.346
189-A	Jan. 22, 1929	270.077	270.075	25.000	135.841	284.5	8,196.7	79.0	10.3	−5.0	8,281.0	60.961	.005	.025	−.077	60.909
195-A	Jan. 31, 1929	270.009	270.016	25.333	137.263	284.3	8,268.4	112.0	1.7	−17.5	8,364.6	60.938	−.002	−.010	−.009	60.919

Even temperature 270°. $\frac{\Delta H}{\Delta \theta}$=5.09 Int. joules per g ° C. Z_{270}=1,328 Int. joules per ° C. α_{270}=4.100 Int. joules per g ° C.

Mean value of β_{270}=61.003 Int. joules per g.

VII. FORMULATION

1. FORMULATION OF CALORIMETRIC DATA

In what has gone before we have the record of the experiments and reduction of the data yielding the values of the three characteristic properties of the fluid, namely:

$$H-L\frac{u}{u'-u},\ L\frac{u'}{u'-u},\ \text{and}\ L\frac{u}{u'-u}$$

denoted by the symbols α, γ, and β, respectively. As a first step in the formulation of the more familiar and more useful thermal properties of steam for engineering purposes, the experimental results are assembled, the values smoothed by means of empirical equations, and the blank spaces filled in by interpolation or by extension, using other experimental data where necessary. This assembly and formulation is given in Table 12. The empirical equations used are also given there. It has not yet been found possible to obtain empirical equations of a simpler form to represent the experimental results to an accuracy warranted by the experimental precision. There is a possibility that a simple formula for expressing the thermal behavior of steam may eventually be discovered. Such a formula would be extremely useful, particularly so if of a form well adapted to thermodynamic calculations and if in agreement with physical facts. In the meanwhile, equations lacking this ideal simplicity of form may be tolerated in the operations of obtaining numerical tabulations of thermal properties which result from experiment. In the present instance fidelity to observation has not been sacrificed to superficial simplicity.

TABLE 12.—*Assembly of observed calorimetric data and comparison with formulation*

Temperature °C.	$\alpha\Big]_0^\theta$			β_θ			γ_θ			L_θ		
	Observed	Calculated	Observed-calculated	Observed	Calculated	Observed-calculated	Observed	Calculated	Observed-calculated	Observed	Calculated	Observed-calculated
	Int. joules/g	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*	*Int. joules/g*
0					[1] (0.016)			2,494.04			2,494.02	
10	41.99	42.01	−0.02		(.023)			2,472.28			2,472.26	
20	83.80	83.80	.00		(.042)			2,450.21			2,450.17	
30	125.51	125.53	−.02		(.074)			2,427.80			2,427.73	
40	167.22	167.23	−.01		(.124)			2,405.02			2,404.90	
50	208.92	208.92	.00		(.200)			2,381.84			2,381.64	
60	250.61	250.61	.00		(.312)			2,358.22			2,357.91	
70	292.30	292.29	.01		(.473)			2,334.12			2,333.65	
80	333.99	333.98	.01		(.697)			2,309.52			2,308.82	
90	375.66	375.66	.00		(1.002)			2,284.38			2,283.38	
100	417.36	417.36	.00	1.409	1.408	0.001	2,258.71	2,258.65	0.06	2,257.30	2,257.24	0.06
110	459.04	459.05	−.01	1.950	1.939	.011		2,232.29			2,230.35	
120	500.72	500.75	−.03	2.613	2.621	−.008		2,205.27			2,202.65	
130	542.39	542.46	−.07	3.488	3.484	.004	2,177.15	2,177.52	−.37	2,173.67	2,174.04	−.37
140	584.09	584.16	−.07	4.570	4.563	.007		2,149.00			2,144.44	
150	625.81	625.87	−.06	5.902	5.891	.011	2,119.64	2,119.65	−.01	2,113.75	2,113.76	−.01
160	667.51	667.57	−.06	7.508	7.510	−.002		2,089.40			2,081.89	
170	709.22	709.21	.01	9.492	9.464	.028	2,058.78	2,058.18	.60	2,049.32	2,048.72	.60
180	750.92	750.94	−.02		11.799			2,025.90			2,014.10	
190	792.58	792.60	−.02		14.569			1,992.46			1,977.89	
200	834.23	834.20	.03	17.821	17.831	−.010	1,957.96	1,957.76	.20	1,940.13	1,939.93	.20
210	875.75	875.72	.03		21.649			1,921.65			1,900.00	
220	917.16	917.17	−.01	26.034	26.090	−.056	1,883.42	1,883.98	−.56	1,857.33	1,857.89	−.56
230	958.51	958.54	−.03	31.210	31.228	−.018		1,844.56			1,813.33	
240	999.83	999.84	−.01	37.170	37.144	.026		1,802.16			1,766.02	
250	1,041.09	1,041.06	.03	43.943	43.925	.018	1,758.88	1,759.51	−.63	1,714.95	1,715.59	−.64
260	1,082.23	1,082.22	.01		51.664			1,713.26			1,661.60	
270	1,123.31	1,123.32	−.01	61.003	61.014	−.011	1,665.21	1,664.52	.69	1,604.20	1,603.51	.69

[1] Values in parentheses are calculated from previously published vapor pressure and specific volume data.

$$\alpha=1.240777\log_{10}\frac{\theta+7}{7}+415.2112\left(\frac{\theta}{100}\right)+0.6912\left(\frac{\theta}{100}\right)^2-0.044874\left(\frac{\theta}{100}\right)^4. \quad \text{(Range 0°–170°.)}$$

$$\alpha=412.91945\left(\frac{\theta}{100}\right)+3.844\left(\frac{\theta}{100}\right)^2-0.5238\left(\frac{\theta}{100}\right)^4+0.0213\left(\frac{\theta}{100}\right)^6. \quad \text{(Range 170°–270°.)}$$

$$\frac{100\beta}{\theta+273.1}=\left(\frac{\theta}{100}\right)^{\frac{10}{3}}\left[0.304065+0.0193\left(\frac{\theta}{100}\right)+0.00662\left(\frac{\theta}{100}\right)\right]+0.04830. \quad \text{(Range 100°–270°.)}$$

$$L=0.002562(374-\theta)^2-5.883(374-\theta)+249.9(374-\theta)^{1/2}-113(374-\theta)^{1/4} \quad \text{(Range 0°–270°.)}$$

Two formulas have been used for α, one of which fits the results in the range from 0° to 170° C. and the other in the range from 170° to 270° C. The formula for β fits the results in the range from 100° to 270° C. The values of β in the range from 0° to 100° C. have been computed from previously published vapor-pressure and liquid-density data.

The experimental values of L have been obtained from the observed values of γ and the smoothed or calculated values of β, using the relation. $L=\gamma-\beta$. The empirical formula for L fits the experimental results to better than 1 part in 2,300. The form of this equation has been chosen in accordance with the usually accepted belief that at the critical temperature (374° C.) the heat of vaporization becomes 0 and approaches this value at a negative infinite rate, and that no real values exist at higher temperatures. Below 100° C. the values given by the equation are in accord with results of other observers.

The calculated values of γ are now obtained from the calculated values of L and β, completing the formulation of the properties measured calorimetrically.

2. DERIVATION OF HEAT CONTENT AND ENTROPY FROM CALORIMETRIC DATA

It is now possible to complete the formulation of heat content and entropy, using the smoothed and extended values of the calorimetric data. The results of these derivations are given in Table 13. The values of heat content of saturated liquid water, H, given in column 2, are obtained as the sums of the values of $\alpha\Big]_0^\theta$ and of $\beta\Big]_0^\theta$, calculated, in Table 12. The values of heat content of saturated vapor H' are equal to $H+L$. The calculation of entropy of the saturated liquid has been made using each of the two formulas:

$$\Phi=\int\frac{\alpha d\Theta}{\Theta^2}+\frac{H}{\Theta}=\int\frac{d\alpha}{\Theta}+\frac{\beta}{\Theta}$$

together with the two empirical equations for α, suited to the two ranges of temperature. Thus, a check was obtained on the accuracy of the computations. These are rather laborious, owing to the complicated form of the α equations. The values of entropy, heat content, α, and β are mutually consistent. The values of entropy of the saturated vapor obtained by adding L/Θ to Φ, which makes these values consistent with the values of L.

TABLE 13.—*Thermal properties of saturated water and steam derived from calorimetric measurements*

Bureau of Standards, February, 1930

Temperature, ° C.	Heat content of liquid, H	Latent heat, L	Heat content of vapor, H'	Entropy— Of liquid Φ	Entropy— Of vapor Φ_1
	Int. Joules/g	*Int. Joules/g*	*Int. Joules/g*	*Int. Joules/g° C.*	*Int. Joules/g° C.*
0	0	2,494.02	2,494.02	0	9.132
10	42.02	2,472.26	2,514.28	.1511	8.884
20	83.83	2,450.17	2,534.00	.2962	8.656
30	125.59	2,427.73	2,553.32	.4363	8.446
40	167.34	2,404.90	2,572.24	.5719	8.253
50	209.11	2,381.64	2,590.75	.7032	8.074
60	250.90	2,357.91	2,608.81	.8305	7.909
70	292.75	2,333.65	2,626.40	.9543	7.756
80	334.66	2,308.82	2,643.48	1.0746	7.613
90	376.65	2,283.38	2,660.03	1.1918	7.480
100	418.75	2,257.24	2,675.99	1.3064	7.356
110	460.97	2,230.35	2,691.32	1.4177	7.240
120	503.36	2,202.65	2,706.01	1.5268	7.130
130	545.93	2,174.04	2,719.97	1.6335	7.027
140	588.71	2,144.44	2,733.15	1.7381	6.929
150	631.75	2,113.76	2,745.51	1.8407	6.837
160	675.06	2,081.89	2,756.95	1.9416	6.749
170	718.66	2,048.72	2,767.38	2.0406	6.664
180	762.72	2,014.10	2,776.82	2.1384	6.584
190	807.15	1,977.89	2,785.04	2.2348	6.506
200	852.02	1,939.93	2,791.95	2.3299	6.430
210	897.35	1,900.00	2,797.35	2.4239	6.357
220	943.24	1,857.89	2,801.13	2.5169	6.285
230	989.75	1,813.33	2,803.08	2.6091	6.213
240	1,036.97	1,766.02	2,802.99	2.7007	6.143
250	1,084.97	1,715.59	2,800.56	2.7919	6.072
260	1,133.87	1,661.60	2,795.47	2.8828	6.000
270	1,184.32	1,603.51	2,787.83	2.9746	5.927

3. DISCUSSION OF ACCURACY

To the user of experimental data consisting of numerical values of physical quantities, it is important to know how trustworthy the figures are. In compiling a table of the properties of steam, over a large range of conditions, from various experimental sources, the choice of the most truthful figures to take as the basis for formulation must be based on a consideration of accuracy of the experimental results.

It is not a simple problem to make an estimate of the accuracy of steam data based on calorimetric measurements, because so many factors enter, each of which contains an element of uncertainty. The experimenter is probably best acquainted with the facts which should be considered in arriving at such an appraisal. Taken together with the evidence included in a description of the work, and making due allowance for possible bias, an experimenter's own judgment as to accuracy may prove useful to the critical reader.

By careful study of all the factors which enter into the measurements, a figure can be assigned to each which represents an estimate of the magnitude of the outstanding systematic error which remains in each factor after all known corrections for standards and calibrations have been applied. Since the signs of these various outstanding sources of systematic error are unknown, they may be considered as combining fortuitously in the final result.

In addition to these, a figure can be deduced for each of the quantities measured calorimetrically, from the differences actually exhibited by individual results, which denotes an estimate of the magnitude of the error of each final result resulting from accidental errors in making the measurements.

Having made these preliminary estimates, it is possible, with the aid of the theory of probability, to combine them and finally obtain a figure which represents an estimate of the limit of variability within which it can be expected the true value lies with any certain degree of likelihood.

Such an analysis has been made of the results of the present investigation, by consideration of every source of error, both systematic and accidental, which seems to have a significant effect. A final estimate has thus been obtained for each of the three thermal properties, H, L, and H'. In each case limits have been estimated such that there is only 1 chance in 100 that the true value lies outside these limits. This is a purely arbitrary way of expressing an index of the accuracy of the results. Such an estimate admits the 1 chance in 100 of the error being greater than the index, and also admits a chance that some important source of systematic error has been overlooked or underestimated.

On this basis it is estimated that there is only 1 chance in 100 that the values given for H differ from the truth by as much as 1 part in 2,000. It is estimated to be equally unlikely that the values given for L and H' are as much as 1.5 joules per gram from the truth in the range of the experiments from 100° to 270° C.

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Without attempting to do justice individually to all who have cheerfully helped this research along, it can be said that whatever success has been attained should be credited to the hearty cooperation of many contributors.

WASHINGTON, March 26, 1930.